

TM-70-2031-1

# TECHNICAL MEMORANDUM

## EQUATIONS OF MOTION OF THE LUNAR ROVING VEHICLE

(NASA-CR-113382) EQUATIONS OF MOTION OF THE  
LUNAR ROVING VEHICLE (Bellcomm, Inc.) 95 p

N79-72068

Unclassified  
00/14 12790

Bellcomm

FF No. 602(C)	(ACCESSION NUMBER) <b>95</b>	(THRU) <b>2</b>
	(PAGES) <b>18</b>	(CODE) <b>19</b>
	(NASA CR OR REF ID NUMBER) <b>CP-113382</b>	(CATEGORY) <b>AGENCIES ONLY</b>
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**BELLCOMM, INC.**

955 L'ENFANT PLAZA NORTH, S.W., WASHINGTON, D.C. 20024

**COVER SHEET FOR TECHNICAL MEMORANDUM**

**TITLE-** Equations of Motion of  
the Lunar Roving Vehicle

TM-70-2031-1

**FILING CASE NO(S)-** 320

**DATE-** March 31, 1970

**AUTHOR(S)-** S. Kaufman

**FILING SUBJECT(S)**  
**(ASSIGNED BY AUTHOR(S))-**

**ABSTRACT**

Equations of motion have been formulated for a four wheeled vehicle with independent suspension, as it traverses over a defined surface characterized by slopes, bumps and craters. External forces are derived for gravity and wheel surface interactions. The equations of motion are solved in the body coordinates of the vehicle. The trajectory of the vehicle is continually monitored.

These equations will be incorporated into a digital computer program whose primary function is to check the dynamic stability of the Lunar Roving Vehicle as it encounters various lunar terrains.

**BELLCOMM, INC.**

955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Equations of Motion of the Lunar  
Roving Vehicle - Case 320

DATE: March 31, 1970

FROM: S. Kaufman  
TM-70-2031-1TECHNICAL MEMORANDUM

Proposed equations of motion are derived for a simulated Lunar Roving Vehicle as it encounters slopes, bumps and craters on the lunar surface. The lunar surface elevation is described as a series of double squared cosine waves superimposed on a linear slope and a constant elevation. Solution of the six degrees-of-freedom model is solved in body coordinates. External forces consist of ground-wheel interactions and gravity forces. If a wheel becomes airborne the system simultaneously gains an inertia force and loses a ground-wheel force. The origin of the body coordinate system need not correspond to the center of gravity; any convenient origin will do.

The orientation of the vehicle with respect to a set of inertia coordinates (fixed on the moon) is shown in Fig. 1. Let  $\bar{I}$ ,  $\bar{J}$ ,  $\bar{K}$  and  $i$ ,  $j$ ,  $k$  be unit vectors along the inertia ( $X$ ,  $Y$ ,  $Z$ ) and body ( $x$ ,  $y$ ,  $z$ ) coordinate system, respectively. The relationship between these vectors can be described in terms of a  $3 \times 3$  direction cosine matrix  $[B]$ . This relationship in terms of the Euler angles is derived in Ref. 1 and is given below:

$$\begin{Bmatrix} \bar{I} \\ \bar{J} \\ \bar{K} \end{Bmatrix} = [B] \begin{Bmatrix} i \\ j \\ k \end{Bmatrix}, \quad (1)$$

where

$$[B] = \begin{bmatrix} \cos\psi\cos\phi - \cos\theta\sin\phi\sin\psi & -\sin\psi\cos\phi - \cos\theta\sin\phi\cos\psi & \sin\theta\sin\phi \\ \cos\psi\sin\phi - \cos\theta\cos\phi\sin\psi & -\sin\psi\sin\phi + \cos\theta\cos\phi\cos\psi & -\sin\theta\cos\phi \\ \sin\theta\sin\psi & \sin\theta\cos\psi & \cos\theta \end{bmatrix}.$$

If we differentiate Eq. (1) with respect to time we obtain the following useful relationship.

$$[\dot{B}] = -[B][C], \quad (2)$$

where

$$[C] = \begin{bmatrix} 0 & \omega_z & -\omega_y \\ -\omega_z & 0 & \omega_x \\ \omega_y & -\omega_x & 0 \end{bmatrix}$$

and  $\omega_x$ ,  $\omega_y$ ,  $\omega_z$  are the angular velocity components along the body axes.

The terrain elevation is defined as a continuous function with a continuous first derivative as follows.

$$\begin{aligned} z_o(x, y) = & g_o + A_o(x - x_o) + B_o(y - y_o) \\ & + \sum_{\alpha=1}^N \delta_\alpha H_\alpha \cos^2 \frac{\pi(x - x_\alpha)}{x_{h\alpha}} \cos^2 \frac{\pi(y - y_\alpha)}{y_{h\alpha}} , \end{aligned} \quad (3)$$

where

$$\delta_\alpha = 1 \quad \text{if} \quad |x - x_\alpha| < \frac{x_{h\alpha}}{2} \quad \text{and} \quad |y - y_\alpha| < \frac{y_{h\alpha}}{2}$$

otherwise  $\delta_\alpha = 0$ . See Fig. 2 for the geometry of a typical  $\alpha$ -bump.

The terrain slopes are obtained by differentiating Eq. (3) or:

$$\begin{aligned} \tan \gamma_x = dz_o/dx = & A_o - 2 \sum_{\alpha=1}^N \frac{\delta_\alpha H_\alpha \pi}{x_{h\alpha}} \cos \pi \frac{(x - x_\alpha)}{x_{h\alpha}} \sin \pi \frac{(x - x_\alpha)}{x_{h\alpha}} \\ & \cos^2 \pi \frac{(y - y_\alpha)}{y_{h\alpha}} , \end{aligned}$$

$$\tan \gamma_y = dz_o/dy = B_o - 2 \sum_{\alpha=1}^N \frac{\delta_\alpha H_\alpha \pi}{Y_{h\alpha}} \cos^2 \pi \frac{(x-x_\alpha)}{X_{h\alpha}} \cos \pi \frac{(y-y_\alpha)}{Y_{h\alpha}}$$

$$\sin \pi \frac{(y-y_\alpha)}{Y_{h\alpha}} . \quad (4)$$

Let

$$L_x = (1 + \tan^2 \gamma_x)^{1/2}$$

and

$$L_y = (1 + \tan^2 \gamma_y)^{1/2} \quad (5)$$

then

$$\begin{aligned} \sin \gamma_x &= \tan \gamma_x / L_x , & \cos \gamma_x &= 1 / L_x \\ \sin \gamma_y &= \tan \gamma_y / L_y , & \cos \gamma_y &= 1 / L_y . \end{aligned} \quad (6)$$

The unit tangent vectors to the terrain surface in the  $\bar{I}-\bar{K}$  and  $\bar{J}-\bar{K}$  planes are given below.

$$\begin{aligned} \bar{t}_x &= \cos \gamma_x \bar{I} + 0 \bar{J} + \sin \gamma_x \bar{K} , \\ \bar{t}_y &= 0 \bar{I} + \cos \gamma_y \bar{J} + \sin \gamma_y \bar{K} . \end{aligned} \quad (7)$$

The outward normal vector to the surface is as follows:

$$\bar{t}_n = \frac{\bar{t}_x \times \bar{t}_y}{|\bar{t}_x \times \bar{t}_y|} = \{a_n\}^t \begin{Bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{Bmatrix} , \quad (8)$$

where

$$\{a_n\}^t = \frac{1}{l_n} [-\sin\gamma_x \cos\gamma_y - \sin\gamma_y \cos\gamma_x \cos\gamma_x \cos\gamma_y] ,$$

and

$$l_n = (\cos^2\gamma_x + \sin^2\gamma_x \cos^2\gamma) ^{1/2} .$$

In Fig. 3 is shown double Ackerman steering geometry for the vehicle. Double Ackerman is merely one possible steering mode, it is to allow the steering angles ( $a_f, f=1,2,3,4$ ) to be set independent of each other and possess their own steering rates. For wheel f the following relationship exists.

$$\begin{Bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{Bmatrix} = [AAA]_f \begin{Bmatrix} \bar{i}_f \\ \bar{j}_f \\ \bar{k} \end{Bmatrix} \quad (9)$$

where

$$[AAA]_f = \begin{bmatrix} \cos a_f & -\sin a_f & 0 \\ \sin a_f & \cos a_f & 0 \\ 0 & 0 & 1 \end{bmatrix} .$$

In terms of the inertia frame of reference, the wheel triad is given as follows:

$$\begin{Bmatrix} \bar{I} \\ \bar{J} \\ \bar{K} \end{Bmatrix} = [\text{AAI}]_f \begin{Bmatrix} \bar{I}_f \\ \bar{J}_f \\ \bar{k} \end{Bmatrix}, \quad (10)$$

where

$$[\text{AAI}]_f = [B][\text{AAA}]_f .$$

The bump or crater dimensions may be of the same size as the wheel diameter. This situation creates a problem in finding a suitable wheel-spring stroke for calculating a ground-vehicle force normal to the wheel surface. The following rational approach has been adopted. With the wheels and suspension fully extended, the circumference of the wheel is searched for apparent locations imbedded beneath the ground surface. A unit vector  $\bar{\tau}_1$  is constructed from the last point (b) to the first point (a) lying beneath the surface (Fig. 4). A slope  $s_1$  is computed, a representative point (e) (mid-point) found with coordinates  $\{XYZ\}_e$ , and the maximum apparent penetration  $\Delta_z(\text{max})$  recorded. Next, a unit vector  $\bar{\tau}_2$ , normal to both  $\bar{\tau}_1$  and the theoretical ground normal  $\bar{t}_{ne}$  (at  $\{X_e Y_e\}$ , Eq. 8) is found as follows:

$$\bar{\tau}_2 = \frac{\bar{t}_{ne} \times \bar{\tau}_1}{|\bar{t}_{ne} \times \bar{\tau}_1|} . \quad (11)$$

The slope along  $\bar{\tau}_2$  is denoted  $s_2$ . An "average" ground normal  $\bar{\tau}_3$  used in subsequent calculations is then computed,

$$\bar{\tau}_3 = \bar{\tau}_2 \times \bar{\tau}_1 . \quad (12)$$

The following relationship can be constructed from Eqs. (11) and (12)

$$\begin{Bmatrix} \bar{\tau}_1 \\ \bar{\tau}_2 \\ \bar{\tau}_3 \end{Bmatrix} = [G]_f \begin{Bmatrix} \bar{I} \\ \bar{J} \\ \bar{K} \end{Bmatrix} . \quad (13)$$

The apparent wheel penetration along  $\bar{\tau}_3$  is denoted  $\Delta\tau_f$  and is computed as follows,

$$\Delta\tau_f = G(3,3)\Delta_z(\max) . \quad (14)$$

Now,

$$\begin{Bmatrix} \bar{\tau}_1 \\ \bar{\tau}_2 \\ \bar{\tau}_3 \end{Bmatrix} = [H]_f \begin{Bmatrix} \bar{i}_f \\ \bar{j}_f \\ \bar{k} \end{Bmatrix} \quad (15)$$

where

$$[H]_f = [G]_f[B] .$$

Next, the body coordinates of point (e) are found relative to the origin of the vehicle. These coordinates will be denoted  $\{xyz\}_e$ . Let  $\{uvw\}$  denote the velocity of the vehicle's origin along the body axes. The velocity of the wheel f at point (e) in the inertia frame of reference is given as follows,

$$\begin{Bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{Bmatrix}_f = [B] \left( \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} - [C] \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}_e \right) . \quad (16)$$

The velocity along the  $\{\bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3\}$  triad is next obtained from Eqs. (13) and (16).

We shall now evaluate the wheel-ground force in the direction  $\bar{\tau}_{3f}$ . Let spring constants along the triad  $\{\bar{i}_f \bar{j}_f \bar{k}\}$  be denoted as  $\{s_{if} s_{jf} s_{kf}\}$ , spring lengths as  $\{\ell_{if} \ell_{jf} \ell_{kf}\}$ , damping constants as  $\{0 0 c_{kf}\}$ , spring deflections as  $\{\Delta u_{if} \Delta u_{jf} \Delta u_{kf}\}$ , and forces as  $\{P_{if} P_{jf} P_{kf}\}$ . Forces along the triad  $\{\bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3\}$  will be denoted  $\{P_{1f} P_{2f} P_{3f}\}$ . The springs will be considered non-linear, that is,

$$s_{\alpha f} = s_{\alpha af} (\alpha = i, j, k) \quad \text{if} \quad \ell_{\alpha f} > |\Delta u_{\alpha f}| ,$$

$$s_{\alpha f} = s_{\alpha bf} \quad \text{if} \quad \ell_{\alpha f} < |\Delta u_{\alpha f}| ,$$

and

$$s_{\alpha bf} \gg s_{\alpha af} .$$

The three spring-deflection relationships are:

$$\begin{aligned} [I] \left\{ \begin{array}{l} P_{if} \\ P_{jf} \\ P_{kf} \end{array} \right\} - \left[ \begin{array}{ccc} s_{if} & & \\ & s_{jf} & \\ & & s_{kf} \end{array} \right] \left\{ \begin{array}{l} \Delta u_{if} \\ \Delta u_{jf} \\ \Delta u_{kf} \end{array} \right\} = - \left[ \begin{array}{l} \delta_{if} (s_{ibf} - s_{iaf}) \ell_{if} \\ \delta_{jf} (s_{jbf} - s_{jaf}) \ell_{jf} \\ \delta_{kf} (s_{kbf} - s_{kaf}) \ell_{kf} \end{array} \right] \\ - \left[ \begin{array}{l} 0 \\ 0 \\ H_f(3,3)v_{\tau_{3f}}c_{kf} \end{array} \right] , \end{aligned} \quad (18)$$

where

$$\delta_{\alpha f} = 1 \quad \text{if} \quad \ell_{\alpha f} < |\Delta u_{\alpha f}|$$

and

$$\delta_{\alpha f} = 0 \quad \text{if} \quad \ell_{\alpha f} > |\Delta u_{\alpha f}| .$$

Equilibrium of tangential forces requires

$$\begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \end{bmatrix} \begin{Bmatrix} P_{if} \\ P_{jf} \\ P_{kf} \end{Bmatrix} = \begin{Bmatrix} P_{1f} \\ P_{2f} \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} . \quad (19)$$

Deflection compatibility requires

$$\begin{bmatrix} H_{31} & H_{32} & H_{33} \end{bmatrix} \begin{Bmatrix} \Delta u_{if} \\ \Delta u_{jf} \\ \Delta u_{kf} \end{Bmatrix} = \Delta_{\tau f} . \quad (20)$$

Equations (18, 19 and 20) are combined into one matrix equation as follows:

$$\{E1\}\{T2\} = \{T1\} \quad (21)$$

where

$$\{T1\} = \left\{ \begin{array}{l} -\delta_{if}(s_{ibf}-s_{iaf})\ell_{if} \\ -\delta_{jf}(s_{jbf}-s_{jaf})\ell_{jf} \\ -\delta_{kf}(s_{kbf}-s_{kaf})\ell_{kf} - H_f(3,3)v_{\tau_{3f}}c_{kf} \\ 0 \\ 0 \\ \Delta_{\tau f} \end{array} \right\} ,$$

$$\{T_2\} = \{\Delta u_{if} \ \Delta u_{jf} \ \Delta u_{kf} \ P_{if} \ P_{jf} \ P_{kf}\} \quad ,$$

and

$$[E_1] = \begin{bmatrix} -s_{if} & 0 & 0 & 1 & 0 & 0 \\ 0 & -s_{jf} & 0 & 0 & 1 & 0 \\ 0 & 0 & -s_{kf} & 0 & 0 & 1 \\ 0 & 0 & 0 & M_{11} & H_{12} & H_{13} \\ 0 & 0 & 0 & M_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} & 0 & 0 & 0 \end{bmatrix} .$$

After solving Eq. 21, the normal ground force is obtained as follows,

$$P_{3f} = H_{31} P_{if} + H_{32} P_{jf} + H_{33} P_{kf} \quad . \quad (22)$$

We will now compute  $P_{2f}$  along  $\bar{\tau}_{2f}$ . Let VSE be some small velocity and  $M_s$  an equivalent coefficient of sidewise friction. Then,

$$P_{2f} = \frac{-v_{\tau 2}}{VSE} M_s P_{3f} \quad \text{for} \quad |\bar{v}_{\tau 2}| < VSE \quad (23)$$

and

$$P_{2f} = \frac{-v_{\tau 2}}{|v_{\tau 2}|} M_s P_{3f} \quad \text{for} \quad |\bar{v}_{\tau 2}| > VSE \quad (24)$$

Forces in the  $\bar{\tau}_{1f}$  direction can come about due to rolling friction, braking friction, or engine torque forces. These forces are mutually exclusive for each wheel and will be denoted  $P_{1f}$ :

Rolling friction,

$$P_{lf} = \frac{-v_{\tau 1}}{|v_{\tau 1}|} M_r P_{3f} , \quad (25)$$

where  $M_r$  is an equivalent coefficient of rolling friction.

Braking force constant,

$$P_{lf} = \frac{-v_{\tau 1}}{|v_{\tau 1}|} \text{ Constant} , \quad (26)$$

and the constant cannot exceed  $M_f P_{3f}$  where  $M_f$  is an equivalent coefficient of friction parallel to  $\vec{i}_f$ . It is assumed that a constant braking torque is being applied.

Engine torque  $T(|v_{\tau 1}|)$ ,

$$P_{lf} = \pm T(|v_{\tau 1}|)/r_w , \quad (27)$$

not to exceed  $M_f P_{3f}$  in absolute value.

The wheel forces rotated in  $\vec{i}$ ,  $\vec{j}$ ,  $\vec{k}$  directions are

$$\left\{ \begin{array}{c} P_i \\ P_j \\ P_k \end{array} \right\}_f = [B]^t [G]_f^t \left\{ \begin{array}{c} P_1 \\ P_2 \\ P_3 \end{array} \right\}_f . \quad (28)$$

The summation of these forces and moments about the origin of the body coordinate system are as follows:

$$\{P_w\} = [D_f] \left\{ \begin{array}{c} P_i \\ P_j \\ P_k \end{array} \right\}_f \quad (29)$$

where

$$[D_f] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -z_e & y_e \\ z_e & 0 & -x_e \\ -y_e & x_e & 0 \end{bmatrix} .$$

For all four wheels,

$$\{P_w\} = \sum_{f=1}^4 \{P_w\}_f . \quad (30)$$

The mass matrix [M] relative to the body coordinate system is defined as follows:

$$[M] = \begin{bmatrix} m & 0 & 0 & 0 & H_z & -H_y \\ m & 0 & -H_z & 0 & H_x & 0 \\ m & H_y & -H_x & 0 & I_{xx} & -I_{xy} \\ & I_{xy} & -I_{yy} & -I_{xz} & & \\ \text{symmetrical} & & I_{yy} & -I_{yz} & & \\ & & & I_{zz} & & \end{bmatrix} , \quad (31)$$

where  $m$  is the sprung mass, and

$$\begin{aligned} H_x &= \int x dm, & H_y &= \int y dm, & H_z &= \int z dm \\ I_{xy} &= \int xy dm, & I_{xz} &= \int xz dm, & I_{yz} &= \int yz dm \\ I_{xx} &= \int (y^2 + z^2) dm, & I_{yy} &= \int (x^2 + z^2) dm, & I_{zz} &= \int (x^2 + y^2) dm \end{aligned}$$

The three linear and three angular momentum components  $\{L\}$  along the body coordinate system is given by the following relationship.

$$\{L\} = [M]\{V\} \quad (32)$$

where,

$$\{V\} = \{u \ v \ w \ \omega_x \ \omega_y \ \omega_z\} \quad .$$

The forces and moment components along the body coordinate axes are given as follows:

$$\{\dot{L}\} = [M]\{\dot{V}\} - \{P_I\} \quad (33)$$

where

$$\{P_I\} = [C_1][M]\{V\} \quad ,$$

and

$$[C_1] = \left[ \begin{array}{c|c} [C] & 0 \\ \hline 0 & [C] \end{array} \right] \quad .$$

Gravity forces act along the negative  $\bar{K}$  axis thru the cg. Gravity force and moment components about the body origin are given below:

$$\{P_g\} = [M]\{-B_{31}g_m \ -B_{32}g_m \ -B_{33}g_m \ 0 \ 0 \ 0\} \quad , \quad (34)$$

where  $g_m$  is the moon's acceleration of gravity.

The equations of motion of the system can now be stated as follows (see Eqs. (30, 33, 34)):

$$\{\dot{V}\} = [M]^{-1}\{P\} \quad (35)$$

where

$$\{P\} = \{P_g\} + \{P_w\} + \{P_I\} .$$

Given  $[B]$  at time  $t=i$ , we shall estimate it at time  $t=i+h$ , where  $h$  is some small time interval and  $\{\omega_x \omega_y \omega_z\}$  is constant during the interval. With this assumption and Equation (2), we can compute the derivatives of  $[B]$  as shown below.

$$\begin{aligned} [B] &= [B] \\ [\dot{B}] &= - [B] [C] \\ [\ddot{B}] &= [B] [C]^2 \\ [\dddot{B}] &= \omega^2 [B] [C] \\ [\cdot\ddot{B}\cdot] &= - \omega^2 [B] [C]^2 \\ [\cdot\ddot{B}\cdot] &= - \omega^4 [B] [C] , \quad \text{etc.} \end{aligned} \quad (36)$$

where

$$\omega^2 = \omega_x^2 + \omega_y^2 + \omega_z^2 .$$

Hence:

$$\begin{aligned} [B]_{i+h} &= [B]_i - h[B] [C] + \frac{h^2}{2!} [B] [C]^2 + \omega^2 \frac{h^3}{3!} [B] [C] \\ &\quad - \omega^2 \frac{h^4}{4!} [B] [C]^2 - \frac{\omega^4 h^5}{5!} [B] [C] , \quad \text{etc.} \\ &= [B]_i \left( [I] - \frac{1}{\omega} [C] \left( \omega h - \frac{(\omega h)^3}{3!} + \frac{(\omega h)^5}{5!} \dots \right) \right. \\ &\quad \left. + \frac{1}{\omega^2} [C]^2 \left( \frac{(\omega h)^2}{2!} - \frac{(\omega h)^4}{4!} + \dots \right) \right) . \end{aligned}$$

We recognize the sine and cosine series in Eq. (36) and obtain the following expression.

$$[B]_{i+h} = [B]_i \left( [I] - \frac{\sin \omega h}{\omega h} h[C] + \frac{\cos \omega h}{(\omega h)^2} (h[C])^2 \right). \quad (37)$$

Eq. (37) has been around awhile (Reference 2). I. Y. Bar-Itzhack, of Bellcomm, has a fortran subroutine (DICOS) available for computing  $[B]_{i+h}$  according to an expression similar to Eq. (37).

The trajectory is updated as follows,

$$\begin{Bmatrix} X_B \\ Y_B \\ Z_B \end{Bmatrix}_{i+h} = \begin{Bmatrix} X_B \\ Y_B \\ Z_B \end{Bmatrix}_i + h/2 \left( [B]_{i+h} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}_{i+h} + [B]_i \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}_i \right), \quad (38)$$

where  $\{X_B \ Y_B \ Z_B\}$  are the inertia coordinates the origin of the vehicle.

Equation (35) is solved by a modified Runge-Kutta algorithm. The strategy is as follows:

1. Compute  $\{P\}_i$  and compute  $\{\dot{V}\}_i = [M]^{-1}\{P\}_i$ . Estimate  $\{V\}_{i+h/2} = \{V\}_i + \frac{h}{2} \{\dot{V}\}_i$ . Update  $[B]$  and  $\{X_B \ Y_B \ Z_B\}$  at  $t = i+h/2$ .
2. Compute  $\{P\}_{i+h/2}^{(1)}$  and  $\{\dot{V}\}_{i+h/2}^{(1)} = [M]^{-1}\{P\}_{i+h/2}^{(1)}$ , and reestimate  $\{V\}_{i+h/2} = \{V\}_i + \frac{h}{4} (\{\dot{V}\}_i + \{\dot{V}\}_{i+h/2}^{(1)})$ . Update  $[B]$  and  $\{X_B \ Y_B \ Z_B\}$  at  $t = i+h/2$ .
3. Recompute  $\{P\}_{i+h/2}^{(2)}$  and  $\{\dot{V}\}_{i+h/2}^{(2)} = [M]^{-1}\{P\}_{i+h/2}^{(2)}$ , and estimate  $\{V\}_{i+h} = \{V\}_i + h\{\dot{V}\}_{i+h/2}^{(2)}$ . Update  $[B]$  and  $\{X_B \ Y_B \ Z_B\}$  at  $t = i+h$ .

4. Compute  $\{P\}_{i+h}$  and  $\{\dot{V}\}_{i+h} = [M]^{-1}\{P\}_{i+h}$

$$\begin{aligned}\{\dot{V}\}_{i+h/2} &= 1/6 \left( \{\dot{V}\}_i + 2\{\dot{V}\}_{i+h/2}^{(1)} \right. \\ &\quad \left. + 2\{\dot{V}\}_{i+h/2}^{(2)} + \{\dot{V}\}_{i+h} \right) ,\end{aligned}$$

$$\{V\}_{i+h} = \{V\}_i + h\{\dot{V}\}_{i+h/2} .$$

Update  $[B]$  and  $\{X_B \ Y_B \ Z_B\}$  at  $t = i+h$ .



S. Kaufman

2031-SK-jct

Attachments

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REFERENCES

1. Goldstein, H., "Classical Mechanics," Addison-Wesley, Chapter IV, 1953.
2. Wilcox, J. C., "A New Algorithm for Strapped-Down Inertial Navigation," IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-3, No. 5, September 1967.

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APPENDIX

A fortran program (ROVER) is presently being created for the Univac 1108. Input to the program will be in NAMELIST format (\$NAME\* starting in column 2). Tentatively, the following input has been adopted.

General Input

X = single array of order 3 of the inertia X,Y,Z coordinates of the origin of the vehicle

Z = double array of order 3x4 containing the body x,y,z coordinates of the wheel hubs (wheel and suspension fully extended)

RW = wheel radius

PHI = initial  $\phi$  angle in degrees (Fig. 1)

THETA = initial  $\theta$  angle in degrees (Fig. 1)

PSI = initial  $\psi$  angle in degrees (Fig. 1)

U = single array of order 6 containing initial rates  
{u v w  $\omega_x$   $\omega_y$   $\omega_z$ }

NINT = number of time intervals for integration

DELTIM = time span of one time interval (maximum)

IPRT = printing integer (print every IPRT time interval)

NDOT = number of locations for additional acceleration output (do not include origin--not to exceed 20)

R = double array (3\*NDOT) of body x,y,z coordinates

GM = moon's acceleration of gravity

Weight Data

CM = constant to divide all weight data (mass conversion constant) CM = 0 implies CM = 1

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Appendix (contd.)

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WM = weight of one unsprung wheel mass; in what follows do not include the unsprung wheel weight

NMASS = 0 implies zero, first, and second weight moments will be supplied (see Eq. 31)

Y(1) = m (total sprung weight rather than sprung mass)

Y(2) = I<sub>xx</sub>

Y(3) = I<sub>yy</sub>

Y(4) = I<sub>zz</sub>

Y(5) = H<sub>x</sub>

Y(6) = H<sub>y</sub>

Y(7) = H<sub>z</sub>

Y(8) = I<sub>xy</sub>

Y(9) = I<sub>xz</sub>

Y(10) = I<sub>yz</sub>

Dimension Y(10)

NMASS = 1 implies detail weight breakdown

NIT = number of masses

A(J,α) = double array of order NIT\*7 of weight data

α = 1, weight

α = 2, x coordinate

α = 3, y coordinate

α = 4, z coordinate

α = 5, local x moment of inertia (about own cg)

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Appendix (contd.)

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$\alpha = 6$ , local y moment of inertia

$\alpha = 7$ , local z moment of inertia DIMENSION A(30,7)

Elevation Data

$$z_o(x, y) = \text{Eq. (3)} + z_{om}^*$$

$$NXY = 0 \text{ implies } z_{om}^* = 0$$

$NXY = 1$ , implies  $z_{om}$  may have a non-zero value

$CXA = X$ , location for  $z_{om}$

$CX\phi = \text{slope parameter,}$

$$z_{om} = CX\phi(X-CXA) \quad \text{if } X > CXA$$

otherwise  $z_{om} = 0$ ,  $X$  being inertia X coordinate

$A\phi = X\text{-slope, } (A_o)$

$B\phi = Y\text{-slope, } (B_o)$

$G\phi = \text{constant amplitude, } (G_o)$

$X\phi = \text{origin for definition of X-slope, } (X_o)$

$Y\phi = \text{origin for definition of Y-slope, } (Y_o)$

$NG = \text{number of } \alpha\text{-bumps/craters}$

$XAL(\beta, \alpha) = \text{double array of order } 2 \times NG \text{ to locate } \alpha\text{-bumps/crater}$

$\beta = 1 \text{ is X-coordinate } (X_\alpha)$

$\beta = 2 \text{ is Y-coordinate } (Y_\alpha)$

---

\*If included,  $z_{om}$  will make  $dz_o/dx$  discontinuous at CXA. the slope  $s_1$ , however, is continuous (see discussion prior to Eq. 11).

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Appendix (contd.)

- 4 -

XHAL( $\beta, \alpha$ ) = double array of order  $2 \times N_G$  for  $\alpha$ -bump/crater diameters;  
 $\beta = 1$  is  $X_{h\alpha}$   
 $\beta = 2$  is  $Y_{h\alpha}$

HAL( $\alpha$ ) = amplitudes ( $H_\alpha$ ) DIMENSION XAL(2,8), XHAL(2,8),  
HAL(8)

Friction Force Data

SF = equivalent coefficient of sidewise friction  
SF = 0 implies frictionless surface (see Eq. 24)

VSE = minimum velocity for full sidewise friction

NR $\phi$ L(f) = single array of order 4;  
0 implies no rolling friction for wheel f,  
1 implies rolling friction for wheel f

RF = coefficient of rolling friction,  
RF = 0 implies zero rolling friction force (Eq. 25)

NBRAK(f) = single array of order 4;  
0 implies no braking force for wheel f,  
1 implies braking force for wheel f

C $\phi$ NS = braking force

BF = coefficient of braking friction,  
BF = 0 implies no braking force (Eq. 26)

NT $\phi$ RQ(f) = single array of order 4;  
0 implies no engine torque for wheel f,  
1 implies engine torque for wheel f (see Eq. 27)

NP = number of pieces of data (not to exceed 6) from which to construct a torque-velocity polynomial of order NP-1

VEL = single array of order NP of velocities

T $\phi$ RQ = single array of order NP of torques

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Appendix (contd.)

- 5 -

VMAX = velocity limit above which torque = 0,  
VMAX=0 implies zero torque

VMIN = velocity limit below which torque equal its  
polynomial value at VMIN

UNIT = torque multiplier; UNIT = 1 will yield  
reverse torque, UNIT = 0 implies zero torque

TF = coefficient of ground friction for engine torque,  
TF = 0 implies zero torque

Suspension Characteristics (see discussion prior to Eq. 20)

N50 = 0 implies maximum input formation

SL( $\alpha$ , f) = spring lengths for wheel f { $\ell_{if}$   $\ell_{jf}$   $\ell_{kf}$ }

SIA( $\alpha$ , f) = soft spring constants for wheel f { $s_{iaf}$   $s_{jaf}$   $s_{kaf}$ }

SIB( $\alpha$ , f) = hard spring constants for wheel f { $s_{ibf}$   $s_{jbf}$   $s_{kbf}$ }

DAMP(f) = damping constant for wheel f DIMENSION SL(3,4),  
SIA(3,4) SIB(3,4), CS(3,4), DAMP(4)

N50 = 1 implies minimum input formation

S(f) =  $\ell_{kf}$

SA(f) =  $s_{kaf}$

SB(f) =  $s_{kbf}$

DAMP(f) =  $c_{kf}$

N50 = 1 also implies the following

$\ell_{if} = \ell_{jf} = 10\ell_{kf} = 10 s(f)$

$s_{iaf} = s_{jaf} = s_{ibf} = s_{jbf} = s_{kbf} = SB(f)$

DIMENSION S(4), SA(4), SB(4), DAMP (4)

STEERING (see Fig. 3)

N100 = 0 implies constant wheel steering angles

AF(f) = constant steering angle for wheel f in degrees,  
if N100=0 the rest of the discussion on steering  
can be by-passed

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Appendix (contd.)

- 6 -

N100 = 1 implies time dependent constant rate double ackerman steering (see Fig. 3)

AG = initial steering angle in degrees for outside front wheel

ST1 = steering rate in degrees/time for outside front wheel

TIMA = initial time for onset of ST1

TIMB = final time for ST1

ST3 = steering rate in degrees/time for outside front wheel

TIMC>TIMB = initial time for onset of ST3

TIMD = final time for ST3; for N100=1 the steering angle, (AP), outside front wheel is given as follows:

AP1 = AG for t<TIMA

AP2 = AG + ST1(t - TIMA) for TIMA < t < TIMB,

AP3 = AG + ST1(TIMA - TIMB) for TIMB < t < TIMC,

AP4 = AP3 + ST3 (t - TIMC) for TIMC < t < TIMD,

AP5 = AP3 + ST3(TIMD - TIMC) for t > TIMD

AST is a maximum outside wheel steering in degrees;  
AP1....AP5 in absolute value will be limited by AST

NSIN = 1 implies sinusoidal double ackerman steering as follows:

AP = AMP\*SIN(ST1(t - T0)) for front outside wheel  
for 0 < t < TSIN,

AMP = amplitude in degrees (positive real only,  
let ST1 take on desired sign),

T<sub>φ</sub> = time lag,

TSIN = final time

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Appendix (contd.)

- 7 -

NTRIM = 1 implies elevation will be automated to trim the vehicle for 1 lunar g. The algorithm goes as follows. In body coordinates construct a vector from the vehicle origin to the ground at the intersection of the wheel centers. Call this vector {ALM}, and:

$$ALX = (Z(1,1)+Z(1,4))/2$$

$$ALY = (Z(2,1)+Z(2,2))/2$$

$$ALZ = -RW+Z(3,1)+DH,  
where DH = mass*GM*B(3,3)/(4*SIA(3,1))$$

Of course this vector assumes elastic and geometry symmetry.

This new origin in inertia coordinates is computed as follows.

$$\begin{Bmatrix} X_\phi \\ Y_\phi \\ G_\phi \end{Bmatrix} = \begin{Bmatrix} X(1) \\ X(2) \\ X(3) \end{Bmatrix} + [B] \begin{Bmatrix} ALX \\ ALY \\ ALZ \end{Bmatrix}$$

We must now compute slopes from a modified B matrix to account for the cg of the vehicle not coinciding with  $X_\phi$ ,  $Y_\phi$ . Call this cg shift  $\theta FF1$  and  $\theta FF2$ , corresponding to X&Y, respectively. This shift causes small angle changes THET1 and THET2, computed as follows:

$$THET1 = EH*\theta FF2/(ALX-Z(1,1))^2,$$

$$THET2 = -EH*\theta FF1/(ALY-Z(2,1))^2$$

The [B] matrix can now be modified and a new direction cosine matrix [B1] computed. The desired slopes are now obtained as follows:

$$A_\phi = -B1(1,3)/B1(3,3),$$

$$B_\phi = -B1(2,3)/B1(3,3)$$

Ground vectors in terms of body vectors are given through the matrix  $[BB] = [B1]^t B$ .  $v_{\tau 3} = 0$  implies  $U(3) = -(BB(3,1)*U(1) + BB(3,2)*U(2))/BB(3,3)$ .

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## Appendix (contd.)

- 8 -

It is felt that the digital program (ROVER) is sufficiently advanced for demonstration. The author would like to express his thanks to Dr. I. Y. Bar-Itzhack of Bellcomm for his subroutine DICOS and to Professor J. S. Vandergraft for his subroutines, QR and TRANSF. As previously explained (Eq. 37), the DICOS subroutine updates the direction cosine matrix. The subroutines QR and TRANSF operate on the output of the UNIVAC 1108 library subroutine TRIDMX. TRIDMX uses Householder's method to transform a symmetric matrix into tri-diagonal form. QR (Francis, Ref. A1) and TRANSF finds the eigenvalues and a set of orthogonal vectors (Refs. A2 and A3) of the tridiagonal matrix and then transforms these vectors into the eigenvectors of the original matrix. The eigenvalue and eigenvector subroutines are used to compute the principal inertias and their direction cosines (for display purposes only).

Other subroutines used with the ROVER program are either library subroutines or were written by the author. These latter subroutines plus the three described above are included with the demonstration problem given below.

The demonstration problem consists of a four wheel vehicle whose cg lies along the z-centroidal axis of the vehicle. The terrain is level, frictional ground forces are zero, initial Euler angles are zero and the initial forward (x) velocity is 10 units. In the vertical direction the vehicle acts as an undamped single-degree-of-freedom oscillator with a period (T) of  $2\pi$  units. The ground and wheels (fully extended) are so positioned as to yield a theoretical Z-trajectory of  $1 - \cos(t)$ .

Some explanation is in order for the selection of the integration interval presently incorporated in the program. The velocity of each wheel (point e in Fig. 4) normal to the ground is continually monitored. A maximum velocity in absolute value (ER) of the 4 wheels is obtained and a characteristic time (TET) =  $.05(RW)/ER$  is obtained (RW is the wheel radius). The number of sub-intervals (L5) of the maximum interval (DELTIM) is computed in integer arithmetic as follows:  $(L5) = \frac{(TET)}{(DELTIM)} + 1$ .

Two maximum time intervals were selected for the demonstration problem: DELTIM = T/40 and T/80. A summary of the Z-trajectory for these two problems is given in Table Al.

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REFERENCES - APPENDIX

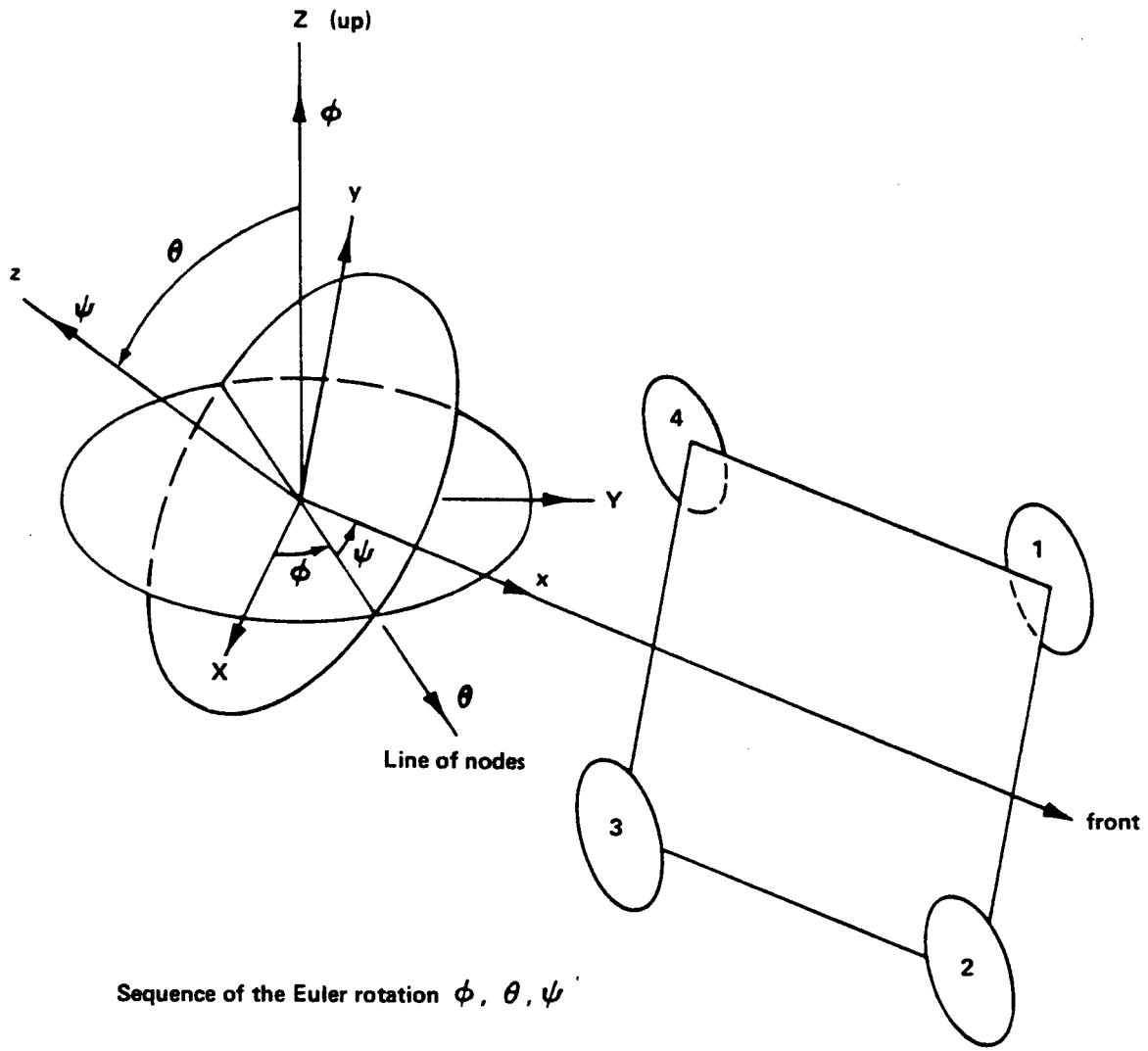
1. J. G. F. Francis, The QR Transformation - A Unitary Analogue to the LR Transformation, Parts 1 and 2, Comp. Journal, 4, 265-271 and 332-345, (1961/1962).
2. J. H. Welsh, Certification of Algorithm 254: Eigenvalues and Eigenvectors of a Real Symmetric Matrix by the QR Method, Comm. ACM, Vol. 10, No. 6, 376-377 (1967).
3. J. S. Vandergraft, Eigenvalues and Eigenvectors of Symmetric Matrices, Case 320, Bellcomm Memorandum B69-07092, July 31, 1969.

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TABLE A1  
COMPUTED Z-TRAJECTORY SUMMARY

Time/Period	Maximum Time Interval (DELTIM)	
	1/80 (2π)	1/40 (2π)
.25	1.000	.998
1.25	.998	.992
2.25	.996	.985
3.25	.995	.979
4.25	.993	.973

Theoretical Z-Trajectory = (1 - cost)



**FIGURE 1 - AXIS ORIENTATION**

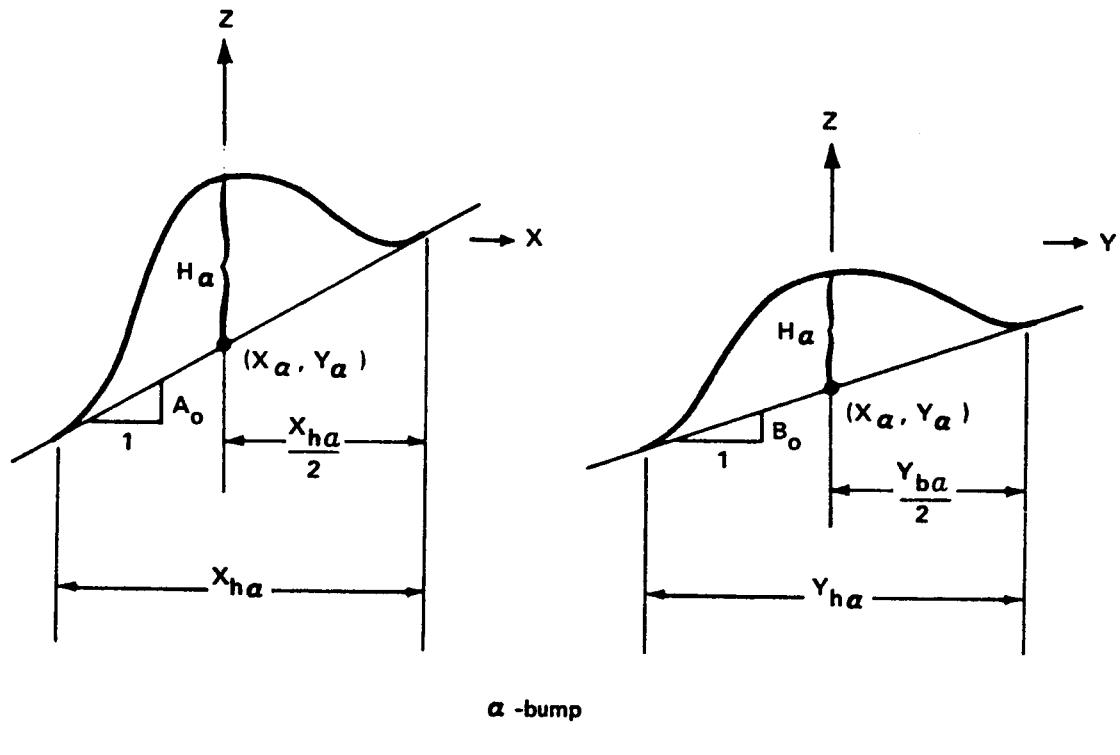
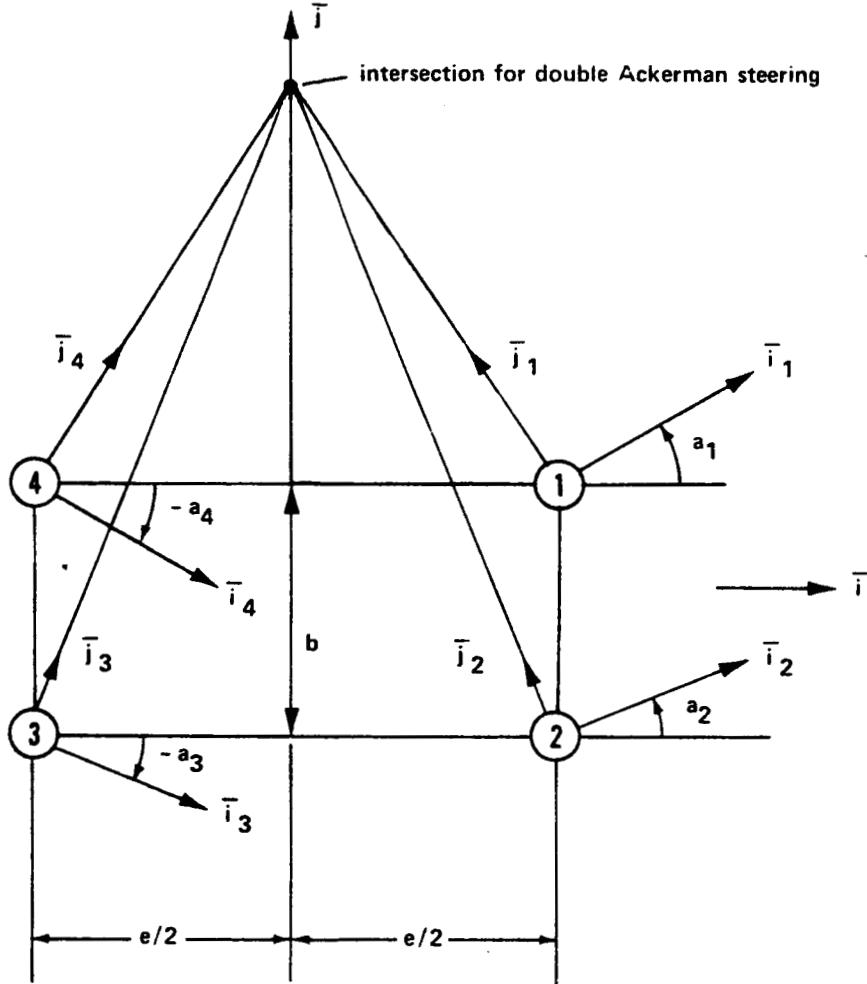


FIGURE 2 -  $\alpha$ -BUMP GEOMETRY



For double Ackerman steering

let  $\beta$  be steering angle - front outside wheel.

$$\beta < 0 \quad a_1 = -a_4 = \beta \quad a_2 = -a_3 = \tan^{-1} \left( e/2 \tan \beta / (e/2 + b \tan \beta) \right)$$

$$\beta > 0 \quad a_2 = -a_3 = \beta \quad a_1 = -a_4 = \tan^{-1} \left( e/2 \tan \beta / (e/2 - b \tan \beta) \right)$$

FIGURE 3 - STEERING GEOMETRY

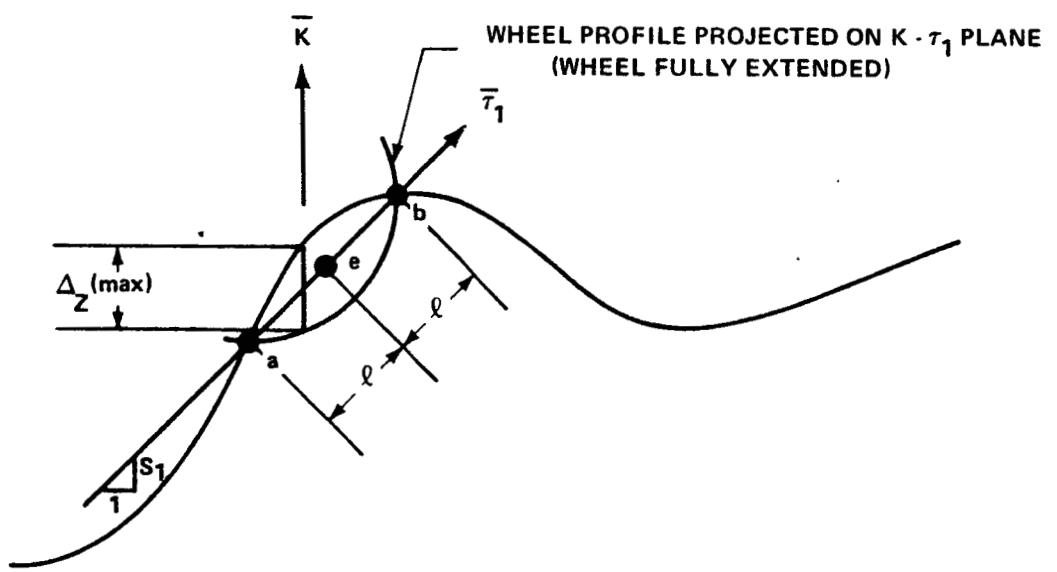


FIGURE 4 - WHEEL-GROUND INTERACTION

HDG DEMO PERIOD=20P1 X(3)=1.0-CDS(T)

ASG,AX

SK3190

PRT,T  
2101-0016

### ROVER•SK3190 ELEMENT TABLE

	NAME	VERSION	TYPE	DATE	TIME	SEG #	SIZE-PRE-TEXT	CYCLES WORD)	PSH/MODE	LOCATION
>	ALPHA		SYMBOLIC	23 MAR 70	21:24:59	1	73	5	0	1792
	RALPH		RELOCATABLE	23 MAR 70	21:25:09	2	71	5	0	1865
	FTORQ		FOR SYMB	23 MAR 70	21:26:10	3	2	5	0	1938
	RFTORQ		RELOCATABLE	23 MAR 70	21:26:14	4	1	4	0	1940
	MVECT		FOR SYMB	23 MAR 70	21:27:05	5	1	2	0	1945
	RMXVECT		RELOCATABLE	23 MAR 70	21:27:09	6	1	4	0	1947
	CROSSP		FOR SYMB	23 MAR 70	21:27:42	7	1	3	0	1952
	RCROSSP		RELOCATABLE	23 MAR 70	21:27:47	8	1	4	0	1955
	DOTVEC		FOR SYMB	23 MAR 70	21:27:52	9	1	2	0	1960
	ROOTVEC		RELOCATABLE	23 MAR 70	21:27:56	10	1	2	0	1962
	TORVEL		FOR SYMB	23 MAR 70	21:28:10	11	1	5	0	1966
	RTORVEL		RELOCATABLE	23 MAR 70	21:28:15	12	1	14	0	1971
	MASS		FOR SYMB	23 MAR 70	21:28:21	13	1	14	0	1986
	RMASS		RELOCATABLE	23 MAR 70	21:28:27	14	1	1U	0	2000
	FORIN		FOR SYMB	23 MAR 70	21:28:31	15	1	3	0	2011
	RFORIN		RELOCATABLE	23 MAR 70	21:28:34	16	1	5	0	2014
	DICOS		FOR SYMB	23 MAR 70	21:35:42	17	1	8	0	2020
	RDICOS		RELOCATABLE	23 MAR 70	21:35:46	18	1	1U	0	2028
	QR		FOR SYMB	23 MAR 70	21:35:52	19	1	24	0	2039
	RQR		RELOCATABLE	23 MAR 70	21:35:57	20	1	25	0	2063
	TRANSF		FOR SYMB	23 MAR 70	21:36:01	21	1	6	0	2087
	RTRANSF		RELOCATABLE	23 MAR 70	21:36:04	22	1	7	0	2095
	GRAY		FOR SYMB	24 MAR 70	17:10:03	23	1	4	1	2103
	RGRAY		RELOCATABLE	24 MAR 70	17:10:07	24	1	3	0	2107
	ROVER		FOR SYMB	26 MAR 70	14:01:50	25	1	119	1	2111
	RROVER		RELOCATABLE	26 MAR 70	14:02:04	26	3	75	0	2230
	MAP		MAP SYMB	26 MAR 70	14:04:19	27	1	5	0	2308
	ABS		ABSOLUTE	26 MAR 70	14:04:39	28	1	452	0	2309
	SPRDEF		FOR SYMB	31 MAR 70	11:25:07	29	87	5	2	2761
	RSPRDEF		RELOCATABLE	31 MAR 70	11:25:18	30	2	96	0	2848
	MAP		MAP SYMB	31 MAR 70	11:26:00	31	1	5	0	2946
	ABS		ABSOLUTE	31 MAR 70	11:26:21	32	452	2947	0	3399

TEXT AVAILABLE LOCATION-

ASSEMBLER PROCEDURE TABLE EMPTY

OBOL PROCEDURE TABLE EMPTY

ORTHRAN PROCEDURE TABLE EMPTY

DEMO PERIOD=20PI X(3)=1

ENTRY POINT TABLE

D NAME	LINK	D NAME	LINK	D NAME	LINK
ALPHA	2	CRUSSP	8	DICOS	16
FORMAINS	26	FTORQ	4	GRAV	10
QR	20	SPRDEF	30	MASS	14
		TORVEL	12	TRANSF	22

I PRT,S SK3190•ROVER

DATE 040170

PAGE 3

D NAME	LINK	D NAME	LINK	D NAME	LINK
		DOTVEC	18	FORIN	16
		MASS	24	MVECT	6
		TRANSF	12		

```

1 10VER=SK3190.RIVER PARAMETER MP=6,M=8,MLT=30,MDOT=20
2  COMMON/ALPHAX/ THE,DELTH,TIN,STI,TSIN,TSE,AMP,PI,L<2,B<2,
3  *NINU,TIMA,TIMH,TINC,TIND,SI,3,AG,AST,Y,AM,GM,
4  *XM,R2,11,LS,NS,    *L1,L2,Z,RW,XAL
5  *C,NG,A,XU,YU,AF,SLA,SLB,SL      *CS,   NRUL,NBRAK,NTUR,RF,BF,
6  *TF,UNIT,VMAX,VMIN,SF,CONS,CV1,NP,
7  *NX,Y,ACO,CXA,VSE,VNDR,XM1,VDO1,VDO2,AB,CD,EF
8  DIMENSION AI(3,3),A5(3),A6(3),A7(3),A9(3),ALU(3)
9  DIMENSION Y(10),ALU(7),B(3,3),VELIMP),TORQIMP),BTORQIMP,MP)
10  DIMENSION Z(3,4),X(3),U(6),L2(4),L1(4),XM(6,6),C(3,3)
11  DIMENSION NROL(4),BRAK(4),NTORQ(4)           ,CVTIMP)
12  DIMENSION R(3,MDOT),
13  DIMENSION THET(3),VDO1(6),VDO2(6)
14  DIMENSION XAL(2,M),XHAL(2,M),HALIM)
15  DIMENSION CS(3,4)
16  DIMENSION S(4),SA(4),SB(4),DAMP(4)
17  DIMENSION RA(3,3),RB(3,3)
18  DIMENSION VNR(4)
19  DIMENSION XM(6,6)           ,JC(MP)
20  DOUBLE PRECISION VE(2)
21  DOUBLE PRECISION D10RIMP,MP)
22  NAMELIST/NAMI/NMASS,NIT,Y,A,PHI,THETA,PSI,VEL,TORQ,NP,CH,MM,Z,X,
23  *U,NINT,DELTH,IPRT,RK,XAL,XHAL,HAL,GO,AO,BU,NG,XO,YU,AF,SLA,SLB,
24  *SL,NROL,NBRAK,NTORQ,RF,BF,TF,UNIT,VMAX,VMIN,SF,
25  *CONS,NP,
26  *GH,R,NSJ,S,SA,SB,DAMP,NIQD,NTRM,MDOT,VSE,
27  *NX,Y,ACO,CXA,TO,AMP,ST3,TIMB,TIMC,TIMD,STI,AG,AST,NSIN,TSIN
28  READ(5,NAMI)
29  P1=3.1415927
30  TSE=(TSIN-T0)*PI*STI/180.
31  IF(1N50)8003,8004,8003
32  R103  CONTINUE
33  DO 8006 I=1,4
34  DO 8005 J=1,2
35  SIA(J,I)=SB(I,I)
36  SIB(J,I)=SA(I,I)
37  SL(J,I)=S(I,I)*10.
38  SIA(3,1)=SA(1,1)
39  SIB(3,1)=SB(1,1)
40  SL(3,1)=S(1,1)
41  R006  CONTINUE
42  BUD4  CONTINUE
43  DO 8008 I=1,4
44  CS(1,1)=DAMP(1)
45  IF(1NMASS)300,301,310
46  J00  DO 340 J=1,NLT
47  Y(1)=Y(1)+A(J,1)
48  Y(2)=Y(2)+A(J,1)*(A(J,3)**2+A(J,5))
49  Y(3)=Y(3)+A(J,1)*(A(J,2)**2+A(J,4))
50  Y(4)=Y(4)+A(J,1)*(A(J,2)**2+A(J,3))
51  Y(5)=Y(5)+A(J,1)*A(J,2)
52  Y(6)=Y(6)+A(J,1)*A(J,3)
53  Y(7)=Y(7)+A(J,1)*A(J,4)
54  Y(8)=Y(8)+A(J,1)*A(J,2)*A(J,3)
55  Y(9)=Y(9)+A(J,1)*A(J,2)*A(J,4)
56  Y(10)=Y(10)+A(J,1)*A(J,2)*A(J,3)

```

```

57      CONTINUE
58      PHI=PHI*PI/180.
59      THETA=THETA*PI/180.
60      PSI=PSI*PI/180.
61      SPH=SIN(PHI)
62      CPH=COS(PHI)
63      STH=SIN(THETA)
64      CTH=COS(THETA)
65      SPS=SIN(PSI)
66      CPS=COS(PSI)
67      B(1,1)=CPS*CPH-CTH*SPH*SPS
68      B(2,1)=CPS*SPH+CTH*CPH*SPS
69      B(3,1)=STH*SPS
70      B(1,2)=-SPS*CPH-CTH*SPH*CPH
71      B(2,2)=-SPS*SPH+CTH*CPH*CPH
72      B(3,2)=STH*CPH
73      B(1,3)=STH*SPH
74      B(2,3)=-STH*CPH
75      B(3,3)=CTH
76      IF(INSINI710U,7101,7100
77      THD=ST1*T0*PI/180.
78      THD=SIN(THD)
79      DO 7102 J=1,4
80      7102 AF(J)=AMP*THD
81      7101 CONTINUE
82      E22=(Z(1,1)-Z(1,4))/2.
83      B22=Z(2,1)-Z(2,2)
84      IF(IN100)9040,9041,9040
85      9040 IF(IAG) 9115,9041,9117
86      CONTINUE
87      9115 AP=AQ*PI/180.
88      DIFF=AST*PI/180.-ARS(AP)
89      IF(DIFF)9142,9143,9143
90      9142 AP=SIGN(LAST,AP)*PI/180.
91      9143 CONTINUE
92      SAP=SIN(AP)
93      CAP=COS(AP)
94      TAP=SAP/CAP
95      D22=E22*TAP
96      F22=E22+B22*TAP
97      G22=D22/F22
98      A22=ATAN(G22)
99      AF(1)=AP*180./PI
100     AF(2)=A22*180./PI
101     AF(3)=-AF(2)
102     AF(4)=-AF(1)
103     GO TO 9041
104     9117 CONTINUE
105     AP=AQ*PI/180.
106     DIFF=AST*PI/180.-ABS(AP)
107     IF(IUFF)9152,9153,9153
108     9152 AP=SIGN(LAST,AP)*PI/180.
109     9153 CONTINUE
110     SAP=SIN(AP)
111     CAP=COS(AP)
112     TAP=SAP/CAP
113     U22=L22*TAP

```

```

114 F22=E22-B22*TAP
115 G22=D22/F22
116 A22=ATAN(G22)
117 AF(1)=A22*180./PI
118 AF(2)=AP=180./PI
119 AF(3)=-AF(2)
120 AF(4)=-AF(1)
121 CONTINUE
122 1FINP)1000,810,811
123 811 CALL TORVEL(VEL,TORQ,CVT,NP,MP,BTORQ,JC,DTOK)
124 810 CONTINUE
125 2 IF(LCM)2,3,2
126 DO 1 I=1,10
127 1 Y11=Y11/CH
128 WM=WM/CH
129 3 CONTINUE
130 CALL MASS(Y,L2,XM,Z,WM)
131 DO 23 L=1,6
132 DO 23 J=1,6
133 DTOR(L,J)=XM(L,J)
134 VE(1)=1.
135 CALL DGJRIDTOR,6,6,6,6,522,JC,VE)
136 22 CONTINUE
137 DO 83 J=1,6
138 DO 83 K=1,6
139 83 XM(I,J,K)=DTOR(J,K)
140 WRITE(6,312)
141 DO 310 I=1,6
142 310 WRITE(6,311)(XM(I,J),J=1,6)
143 312 FORMAT(1/1H ,30HSPRING MASS MATRIX (NO WHEELS))
144 311 FORMAT(1/1H ,6(1PE16.7))
145 XBAR=Y(5)/Y(1)
146 YBAR=Y(6)/Y(1)
147 ZBAR=Y(7)/Y(1)
148 XX=(Y(2)-Y(1))*(YBAR**2+ZBAR**2)
149 YY=(Y(3)-Y(1))*(ZBAR**2+XBAR**2)
150 ZZ=(Y(4)-Y(1))*(XBAR**2+YBAR**2)
151 XY=Y(8)-Y(1)*XBAR*YBAR
152 XZ=Y(9)-Y(1)*XBAR*ZBAR
153 YZ=Y(10)-Y(1)*ZBAR*YBAR
154 AI(1,1)=XX
155 AI(2,2)=YY
156 AI(3,3)=ZZ
157 AI(1,2)=-XY
158 AI(1,3)=-XZ
159 AI(2,3)=-YZ
160 AI(2,1)=AI(1,2)
161 AI(3,1)=AI(1,3)
162 AI(3,2)=AI(2,3)
163 CALL TRIDMX(3,3,A1,A5,A6)
164 CALL QR(3,A5,A6,A7,A2,A8,A9,A10,J)
165 CALL TRANS(3,A1,A2,A8,3)
166 WRITE(6,405)XBAR,YBAR,ZBAR
167 405U FORMAT(1/1H ,5HXBAH=,1PE16.7,5X,5HYBAH=,1PT16.7,5A,5HZBAR=,
168 ,1PE16.7)
169 405I WRITE(6,405I)
170 405I FORMAT(1/1H ,35Hmoment of inertia tensor about CG)
```

```

171      WRITE(6,6052)XXI,YYI,ZZI,XI,YI,ZI,YZI
172      6052   FORMAT(1/1H '4HIXX'=1PE14.7,2X,4H1YY=1PE14.7,2X,4HIZZ=1PE14.7,
173      .2X,4HIXY=1PE14.7,2X,4HIXZ=1PE14.7,2X,4HYIZ=1PE14.7)
174      WRITE(6,6053)
175      6053   FORMAT(1/1H ,36HROTATION VECTOR & PRINCIPAL INERTIAS)
176      DO 6654 J=1,3
177      6654   WRITE(6,6055)A7(IJ),(A2(K,J),K=1,3)
178      6055   FORMAT(1/1H ,18HPRI,CTPAL (INERTIA,1PE16.7,10X,3(1PE16.7))
179      DH=Y(11)*GM*B(3,3)/(4.5*I(3,1))
180      AL3=-RW+Z(3,1)*DH
181      AL1=(Z(1,1)+Z(1,4))/2.
182      AL2=(Z(2,1)+Z(2,2))/2.
183      OFF1=XBAR-AL1
184      OFF2=YBAR-AL2
185      BLX=AL1-Z(1,1)
186      BLY=AL2-Z(2,1)
187      THET(1)=DH*OFF2/(BLY**2)
188      THET(2)=-DH*OFF1/(BLX**2)
189      THET(3)=D0
190      DO 4850 J=1,3
191      DO 4850 K=1,3
192      B1(J,K)=B1(J,K)
193      CALL DICOS(THET,B1)
194      OFF3=ZBAR-AL3
195      WRITE(6,4851)
196      4851   FORMAT(1/1H ,111HC RELATIVE TO WHEEL CENTER ORIGIN AT GROUND
197      ,AT TIME=0 (BODY COORDINATES) ASSUMING WHEELS HAVE BEEN TRIMMED)
198      WRITE(6,4852)OFF1,OFF2,OFF3
199      4852   FORMAT(1H ,2HX=1PE16.7,5X,2HY=1PE16.7,5X,2HZ=1PE16.7)
200      IF(INTRIM)9060,9061,9060
201      9060  CONTINUE
202      X0=X(1)+AL1*B(1,1)+AL3*B(1,3)+AL2*B(1,2)
203      Y0=X(2)+AL1*B(2,1)+AL3*B(2,3)+AL2*B(2,2)
204      G0=X(3)+AL1*B(3,1)+AL3*B(3,3)+AL2*B(3,2)
205      A0=B1(1,3)/B1(3,3)
206      B0=B1(2,3)/B1(3,3)
207      CALL MXTRN(B1,BA,3,3,3,3)
208      CALL MXMLT(BA,B,BB,3,3,3,3)
209      U(3)=-(BB(3,1))*U(1)+BB(3,2)*U(2)+BB(3,3)
210      WRITE(6,9062)GO,A0,B0,X0,Y0
211      9062   FORMAT(1/1H ,3HGO,1PE16.7,5X,3HA0=,1PE16.7,5X,3HB0=,1PE16.7,5X,
212      .3HX0=1PE16.7,5X,3HY0=,1PE16.7)
213      WRITE(6,9063)U(3)
214      9063   FORMAT(1/1H ,5HU(3)=,1PE16.7)
215      9061  CONTINUE
216      NA=NINT+1
217      LS=1
218      DO 100 I=1,NA
219      11=I-1
220      TIM=I*DELTIM
221      TNE=TIM-TO
222      TNF=TNE-TSIN
223      IF(TNF)1703,7104,7104
224      7104  NSIN=0
225      7103  CONTINUE
226      12=I/1PRPT
227      RI=I

```

DEMO PERIOD=2\*PI X(3)=1

```

228      R2=IPRT
229      R3=R1/R2
230      R1=12
231      R2=R3-R1
232      ER=ABS(VNDR(1))
233      DO 3600 J=2,4
234      ES=ABS(VNDR(J))-ER
235      IF(ES) 3600,3600,3601
236      ER=ABS(VNDR(J))
237      3600 CONTINUE
238      IF(ER) 1000,4320,3603
239      3603 TET=.05*RW/ER
240      LS=DELTIM/TETO
241      GO TO 4305
242      LS=1
243      4305 CONTINUE
244      TEL=LS
245      TRL=1./TEL
246      IF(LS=1) 1000,4306,4307
247      4307 DELTIM=DELTIM*TRL
248      4308 CONTINUE
249      DO 3403 NS=1,L5
250      L6=NS-1
251      ATI=L6*DELTIM
252      TIM=TIM+ATI
253      TNE=TNE+ATI
254      EM=B(3,3)
255      IF(EM.GE.0.2D)GO TO 40
256      WRITE(6,421) TIM
257      421 FORMAT(1H1,44HBODY Z IS ALMOST NORMAL TO INERTIA Z TIME=,
258      *1PE16.7,7HSECONDS)
259      GO TO 1000
260      40 CONTINUE
261      CALL ALPHA
262      IF(NS=L5) 3403,3411,1000
263      3411 DELTIM=DELTIM*TEL
264      3403 CONTINUE
265      100 CONTINUE
266      1000 CONTINUE
267      END

```

OVERSK319U.ALPHA

SUBROUTINE ALPHA

```

1      PARAMETER H=8,MP=6,MDOT=20
2      COMMON/ALPHAX/ TNE,DELTIM,TIM,ST1,TSIN,AMP,P1,E22,B22,
3      *N100,TIMA,TIMB,TIMC,TIMD,ST3,AG,AST,Y,MM,GM
4      *AM,R2,L1,L5,NS, R,L1,L2,Z,RM,XAL,XHAL,HAL,BO,AU,GO,U,
5      *C,NG,K,XO,YO,AF,SIA,SIB,SL ,CS, NRUL,NBRAK,NTORY,RF,BF,
6      *TF,UNIT,VMAX,VMIN,UF ,CONS,CVT,NP,
7      *NXY,XCO,CXA,VSE,VNOR,XMI,VDO1,VDO2,AD,CD,EF
8
9      DIMENSION Y(10),VNCR(4) ,B(3,3)
10     DIMENSION DU(6),
11     DIMENSION Z(3,4),X(3),U(6),L2(4),L1(4),XM(6,6),C(3,3),SA(3,MDOT)
12     DIMENSION XAL(2,M),XHAL(2,M),HAL(M),
13     DIMENSION LMIN(4),
14     DIMENSION NROL(4),NBRAK(4),NTORQ(4),PWF(6),CVT(MP),XMI(6,6)
15     DIMENSION VE(12),GR(6),FINE(6),EVECT(6),VOUT(6),CTDOT(3,3)
16     DIMENSION R13,MDOT,
17     DIMENSION THET(3),VU01(6),VU02(6),VU03(6),JCIMP,AN(3,3,4)
18     DIMENSION PING(3,4),BVEC(3)
19     DOUBLE PRECISION DTURIMP,MP,VE
20     DO 2000 IF=1,4
21     C(1,2)=U(6)
22     C(1,3)=U(5)
23     C(2,1)=U(6)
24     C(2,3)=U(4)
25     C(3,1)=U(5)
26     C(3,2)=U(4)
27     IAN=IF-1
28     IB=IF-2
29     IC=IF-3
30     ID=IF-4
31     IF(NSIN)7201,7200,7201
32     CONTINUE
33     C STEERING ANGLE OUTSIDE FRONT WHEEL = AMP*SIN(ST1)*INE
34     C STOP TURNING AFTER TSIN
35     AFF=AF11
36     IF (AFF.GE.1.E-06.OR.AFF.LE.-1.E-06) GO TO 8880
37     IF (ST1) 7202,8201,7203
38     NSIN=0
39     GO TO 7200
40     8880 IF (AFF<1.E-06) GO TO 7203
41     7202 CONTINUE
42     IF (IAF) 7204,7205,7204
43     7205 AP=AF11
44     GO TO 7206
45     7204 IF (IB) 7207,7208,7207
46     7208 TNG=INE+.5*DELTIM
47     TNF=TNG-TS1
48     IF (INF) 7209,7210,7210
49     7210 NSIN=U
50     AP=AMP*SIN(TSE)
51     GO TO 7206
52     7209 CONTINUE
53     THD=ST1*TNG*P1/180.
54     AP=AMP*SIN(THD)
55     GO TO 7206
56     7207 IF (IC) 7211,7206,7211

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57   7211 TNG=TNE+DELTIM
58   TNF=TNG=TSIN
59   IF(INF)7212,7213,7213
60   NSIN=0
61   AP=AMP*SIN(ITSE)
62   GO TO 7206
63   CONTINUE
64   THD=STI*TNG*PI/180.
65   AP=AMP*SIN(ITMD)
66   CONTINUE
67   AP=AP*PI/180U.
68   SAP=SIN(AP)
69   CAP=COS(AP)
70   TAP=SAP/CAP
71   D22=E22*TAP
72   F22=E22+B22*TAP
73   G22=D22/F22
74   A22=ATAN(G22)
75   AF(1)=AP*180*/PI
76   AF(2)=A22*180./PI
77   AF(3)=AF(2)
78   AF(4)=AF(1)
79   GO TO 7200
80   CONTINUE
81   IF(LIA)7214,7215,7214
82   AP=AF(2)
83   GO TO 7216
84   7214 IF(1B)7217,7218,7217
85   7218 TNG=TNE+.5*DELTIM
86   TNF=TNG=TSIN
87   IF(INF)7219,7220,7220
88   NSIN=0
89   AP=AMP*SIN(ITSE)
90   GO TO 7216
91   CONTINUE
92   THD=STI*TNG*PI/180.
93   AP=AMP*SIN(ITMD)
94   GO TO 7216
95   7217 IF(1C)7221,7200, 7221
96   TNG=TNE+DELTIM
97   TNF=TNG=TSIN
98   IF(INF)7222,7223,7223
99   NSIN=0
100  AP=AMP*SIN(ITSE)
101  GO TO 7216
102  CONTINUE
103  THD=STI*TNG*PI/180.
104  AP=AMP*SIN(ITMD)
105  CONTINUE
106  AP=AP*PI/180U.
107  SAP=SIN(AP)
108  CAP=COS(AP)
109  TAP=SAP/CAP
110  D22=E22*TAP
111  F22=D22/B22*TAP
112  G22=A22=ATAN(G22)
113

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114 AF(1)=A22*180./PI
115 AF(2)=AP*180./PI
116 AF(3)=AF(2)
117 AF(4)=AF(1)

118 7200 CONTINUE
119 IF(IN100)638U,6054,6387
120 638U CONTINUE
121 IF(1A)6320,6321,6320
122 TTR=D*U
123 GO TO 6326
124 6320 IF(1B)6323,6324,6323
125 TIS=TIM+5*DELTIM
126 TTR=5*DELTIM
127 GO TO 6326
128 6323 IF(1C)6325,3980,6325
129 6325 TIS=TIM+DELTIM
130 TTR=5*DELTIM
131 GO TO 6326
132 3980 TTR=D*U
133 6326 CONTINUE
134 IF(TIS.LT.TIMA.AND.TIS.GE.TIMB)GO TO 6050
135 ST2=ST1
136 GO TO 6054
137 6050 IF(TIS.GE.TIMC.AND.TIS.LT.TIMD)GO TO 6051
138 N100=0
139 GO TO 6054
140 6051 ST2=ST1
141 6054 CONTINUE
142 IF(IN100)9010,9011,9010
143 9010 CONTINUE
144 IF(AF(1))9030,9030,9031
145 9030 CONTINUE
146 AP=AF(1)+ST2*TTR
147 IF(IN100)9080,9081,9080
148 9081 AP=AG+ST1*(TIMB-TIMA)+ST3*(TMD-TMC)
149 9080 CONTINUE
150 IF(TIS.LT.TIMA.AND.TIS.GE.TIMB)GO TO 9091
151 GO TO 9092
152 9091 AP=AG+ST1*(TIMB-TIMA)
153 9092 CONTINUE
154 DIFF=AST-ABS(AP)
155 IF (DIFF)6060,6060,6061
156 6060 AP=SIGN(AST,AP)
157 6061 CONTINUE
158 AP=AP*PI/180.
159 TAP=SIN(AP)/COS(AP)
160 D22=E22*TAP
161 F22=E22*B22*TAP
162 G22=D22/F22
163 A22=ATAN(G22)
164 AF(1)=AP*180./PI
165 AF(2)=A22*180./PI
166 AF(3)=AF(2)
167 AF(4)=AF(1)
168 GO TO 9011
169 9031 CONTINUE
170 AP=AF(12)+ST2*TTR

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171      IF(N100)9082,9083,9082
172      AP=AG+ST1*(TIMB-TIMA)+ST3*(T1MD-TIMC)
173      CONTINUE
174      IF(TIS.LT.TIMC.AND.TIS.GE.TIMB)GO TO 9094
175      GO TO 9094
176      9093 AP=AG+ST1*(TIMB-TIMA)
177      9094 CONTINUE
178      DIFF=AST-ABS(AP)
179      IF(DIFF16070,6070,6071
180      6070 AP=SIGN(AST,AP)
181      6071 CONTINUE
182      AP=AP•PI/IBU.
183      TAP=SIN(AP)/COS(AP)
184      G22=E22•TAP/(E22-B2•TAP)
185      A22=ATAN(G22)
186      AF(1)=A22•IBU./PI
187      AF(2)=AP•IBU./PI
188      AF(3)=-AF(2)
189      AF(4)=-AF(1)
190      9011 CONTINUE
191      CALL SPRODEF(L1,L2,Z,RW,XAL,M,XHAL,BO,AO,GU,U,
192      *C,NG,X,XO,YO,AF,SIA,SIB,SL,WIN,CS,PNF,NROL,NBRAK,NTORQ,RF,BF,
193      *TF,UNIT,VMAX,VMIN,SF,CONS,CVT,NP,MP,AN,DT,PNG,PNF,BDI,
194      *NXY,XCO,CXA,VSE,VNOR)
195      DO 20 L=1,4
196      L3=L2(L)-L1(L)
197      IF(L3)21,20,21
198      20 CONTINUE
199      199  GO TO 22
200      200  CALL MASSIV,L2,XM,7,WM)
201      201  DO 23 L=1,6
202      202  DO 23 J=1,6
203      203  DTOR(L,J)=XM(L,J)
204      204  VEL1)=1.
205      205  CALL DGJR(DTOR,6,6,6,6,$2200,JC,VE)
206      206  2200 CONTINUE
207      207  DO 83 J=1,6
208      208  DO 83 K=1,6
209      209  83 XM(J,K)=DTOR(J,K)
210      210  CONTINUE
211      211  CALL GRAVIB,XM,GM,GR)
212      212  CALL FORINC,XM,U,FINE)
213      213  DO 10 L=1,6
214      214  10 EVEC(L)=FINE(L)+GR(L)+PNF(L)
215      215  IP(1A)701,700
216      216  CALL MAVECT(XM,EVEC,VDOT,6,6,6,6,6)
217      217  IF(ABS(R2).GE.1.E-07)GO TO 110
218      218  101  CONTINUE
219      219  IF(INS=1) 10000,3470,110
220      220  3470 CONTINUE
221      221  WRITE(16,102)TIM,1115
222      222  102  FORMAT(//1H , 6HTIME =,1PE16.7,2X,7HSECONDS,15,1A,
223      *14H TIME INTERVALS,2X,15,13HSUB INTERVALS)
224      224  *WRITE(16,103)
225      225  103  FORMAT(1/H , 42HBODY TRANSLATIONAL AND ANGULAR VELOCITIES)
226      226  WRITE(6,104)U(L),L=1,6
227      227  FORMAT(1/H , 61PE16.7)
228      228  104  FORMAT(1/H , 61PE16.7)

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228      WRITE(6,105)
229      105  FORMAT (/1H *16HX,Y,Z THAJECT0n7)
230      WRITE(6,106)(X(I),L=1,3)
231      106  FORMAT (1H , 311PE16,7)
232      WRITE(6,107)
233      107  FORMAT (/1H *23HCOLLECTION COSINE MATRIX)
234      DO 108 J=1,J
235      DO 109 K=1,K
236      109  AVEC(K)=B(J,K)
237      WRITE(6,106)AVEC(L),L=1,3
238      108  CONTINUE
239      WRITE(6,111)
240      111  FORMAT (/1H *44HBODY TRANSLATIONAL AND ANGULAR ACCELERATIONS)
241      WRITE(6,104)(VDOT(I),L=1,6)
242      *'RITE(6,112)(L21L),L=1,4)
243      112  FORMAT (/1H *19HWHEEL INDICATOR L2,4(13))
244      WRITE(6,116)
245      DO 113 J=1,J
246      113  WRITE(6,119)(PNGL(J),L=1,3)
247      118  FORMAT (/1H *27HWHEEL-GROUND FORCES 1-BODY,10X,6HJ-BODY,10X,
248      *6HK-BODY)
249      119  FORMAT (/1H *14X,311PE16,7)
250      WRITE(6,901)(AF(L),L=1,4)
251      901  FORMAT (/1H *23HSTEERING ANGLES DEGREES,411PE16,7)
252      IF(INDOT) 1000,751,750
253      CONTINUE
254      CTDOT(1,2)=VDOT(6)
255      CTDOT(2,1)=VDOT(6)
256      CTDOT(1,3)=VDOT(5)
257      CTDOT(3,1)=VDOT(5)
258      CTDOT(2,3)=VDOT(4)
259      CTDOT(3,2)=VDOT(4)
260      CALL MMMLT(CTDOT,R,SAA,3,3,NDOT,3,3)
261      DO 330 J=1,NDOT
262      DO 330 K=1,3
263      330  TIK,J)=SAA(K,J)+VDOT(K)
264      WRITE(6,331)
265      331  FORMAT (/1H *4SHACCELERATIONS EXTRA POINTS BODY AXES )
266      DO 332 J=1,NDOT
267      332  WRITE(6,333)IT(K,J),K=1,3)
268      333  FORMAT (/1H *311PE16,7)
269      751  CONTINUE
270      WRITE(6,334)(FINE(K),K=1,6)
271      WRITE(6,335)(GRIK),K=1,6)
272      WRITE(6,336)(PF(K),K=1,6)
273      334  FORMAT (/1H *36HNON LINEAR INERTIA FORCES RODY AXES,611PE13,6)
274      335  FORMAT (/1H *36HGRAVITY FORCES
275      336  FORMAT (/1H *36HWHEEL FORCES
276      110  CONTINUE
277      DO 702 J=1,6
278      U1(J)=U(J)
279      702  DO 703 K=1,9
280      DO 703 J=1,3
281      XI(K)=X(K)
282      B1(K,J)=B1K,J)
283      DO 704 J=1,9
284      U(J)=U(J)+VDT(J)*DELTIME*5

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285      DO 705 J=1,3
286      J1=3+J
287      THET(IJ)=(U(IJ))+U(IJ))•DELTIM•.25
288      CALL DICOS (THET,B)
289      DO 706 J=1,3
290      X(IJ)=X(IJ)
291      DO 706 K=1,3
292      X(IJ)=X(IJ)+(B(IJ,K)•U(IK)+B(J,K)•U(K))•DELTIM•.25
293      GD TO 2000
294      700  CONTINUE
295      IF(LIB1710,711,710
296      711  CALL MXVECT(XM1,EVECT,VDO1,6,6,6,6)
297      DO 712 J=1,6
298      712  U(IJ)=U(IJ)+VUDOT(J)+VDO1(J)•DELTIM•.25
299      DO 713 J=1,3
300      J1=3+J
301      713  THET(IJ)=U(IJ)+U(IJ))•DELTIM•.25
302      DO 714 J=1,3
303      DO 714 K=1,3
304      B(IJ,K)=B(IJ,K)
305      CALL DICOS (THET,B)
306      DO 715 J=1,3
307      X(IJ)=X(IJ)
308      DO 715 K=1,3
309      X(IJ)=X(IJ)+(B(IJ,K)•U(IK)+B(J,K)•U(K))•DELTIM•.25
310      GO TO 2000
311      710  CONTINUE
312      IF(LIC1717,718,717
313      718  CALL MXVECT(XM1,EVECT,VDO2,6,6,6,6)
314      DO 719 J=1,6
315      719  U(IJ)=U(IJ)+VDO2(J)•DELTIM
316      DO 720 J=1,3
317      J1=3+J
318      720  THET(IJ)=U(IJ)+U(IJ))•DELTIM•.5
319      DO 721 J=1,3
320      DO 721 K=1,3
321      B(IJ,K)=B(IJ,K)
322      CALL DICOS (THET,B)
323      DO 722 K=1,3
324      X(IJ)=X(IJ)
325      DO 722 K=1,3
326      X(IJ)=X(IJ)+(B(IJ,K)•U(IK)+B(J,K)•U(K))•DELTIM•.5
327      GO TO 2000
328      717  CONTINUE
329      CALL MXVECT(XM1,EVECT,VDO3,6,6,6,6)
330      DO 730 J=1,6
331      U(IJ)=VUDOT(IJ)+VDO3(J)•2.0•VDO3(IJ)) •DELTIM/6.
332      730  U(IJ)=U(IJ)+U(IJ)
333      DO 731 J=1,3
334      J1=3+J
335      731  THET(IJ)=U(IJ)+U(IJ))•DELTIM•.5
336      DO 732 J=1,3
337      DO 732 K=1,3
338      B(IJ,K)=B(IJ,K)
339      CALL DICOS (THET,B)
340      DO 733 J=1,3
341      X(IJ)=X(IJ)

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```
342      UO 733 K=1,3
343      733   X(J)=X(J)+(B1(J,K)*U1(K)+B(J,K)*U(K))*DELTIM*5
344      2000  CONTINUE
345      1000  CONTINUE
346      RETURN
347      END
```

```
> PRT.S SK3190.SPRDEF
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```

1  OVER*SK3190.SPRDEF
2      SUBROUTINE SPRDEF(B,L1,L2,Z,RW,X-L,H,XHAL,HAL,BU,AC,JO,U,
3      *C,NG,X,XO,YO,AF,SA,SIR,SL,IWIN ,CS,PNF,NHUL,NBRAK,NTUR,RF,MF,
4      *TF,UNIT,VMAX,VMIN,SF ,CONS,CVT,NP,MP,AN,UT,PNF,PNF,UDL,
5      *NXY,ACD,CXA,VSE,VNOR)
6      DOUBLE PRECISION V1,E3(6,6)
7      DIMENSION BSTAR(3),HIA(3),AI(4)
8      DIMENSION H1(3,3)
9      DIMENSION VAI(626,5)
10     DIMENSION FUISP(6),BDIS(6),BDI(6,4),YAA(3)
11     DIMENSION B(3,3),BT(3,3),CT(3,3),L2(4),L1(4),AN(3,3,4)
12     DIMENSION AF(4),ZA(3),Z(3,4),AAA(3,3),AAC(3,3),AAT(3,3)
13     DIMENSION AX(626,1),VF(3),VG(3),XAL(2,M),HAL(M),U(6)
14     DIMENSION DZ(4),TL(3),TK(3),T2(3),T3(3),WU(3),WV(3)
15     DIMENSION VS(3),VE(3),VA(3),VB(3),VL(3),VBB(3),TVB(3),VI(3)
16     DIMENSION YA(3),G(3,3),H(3,3),E(6,6),E2(6,6),F1(6),F2(6),V(3)
17     DIMENSION VI(2),FQ(3),SIA(3,4),SIB(3,4),SL(3,4),CS(3,4)
18     DIMENSION NA(3,4),DR(3),IWIN(4),PNF(3,4),VTAU(3)
19     DIMENSION NROL(4),NBRAK(4),NTOKQ(4),CVT(MP),GB(3,3),GBT(3,3)
20     DIMENSION PNR(3),PNI(3),D(6,3),PNJ(6),PNF(6),DT(4),PNQ(J,4)
21     DO BU000 1=1,6
22     PNJ(1)=0.0
23     R1000 PNF(1)=0.0
24     DO BU001 I=1,3
25     DO BU001 J=1,3
26     DO BU001 K=1,3
27     AN(1,J,K)=0.0
28     DO BU002 I=1,3
29     DO BU002 J=1,4
30     PNG(1,J)=0.0
31     BD111,J)=0.0
32     PNF(I,J)=0.0
33     CALL MTRN(C,CT,J,3,3,3)
34     CALL MTRN(B,BT,3,3,3)
35     PI=3.1415927
36     DO 4 1=1,4
37     L1(1)=L2(1)
38     IWIN(1)=0
39     L2(1)=0
40     DO 2 J=1,3
41     ZA(J)=Z(J,1)
42     CALL MXVECT(B,ZA,ZZ,3,3,3)
43     DO 3 J=1,3
44     XC(J)=X(J)+Z2(J)
45     AI(1)=PI*AF(1)/180.
46     CI=COS(AI(1))
47     SI=SIN(AI(1))
48     C
49     C (IB,JB,KB)=AAA(IF,JF,KB)
50     C
51     AAA(1,1)=CI
52     AAA(1,2)=SI
53     AAA(2,1)=SI
54     AAA(2,2)=CI
55     AAA(3,3)=1.
56     CALL MMMLT(B,AAA,AA1,3,3,3,3)

```

```

57   C   (I,J,K)=A111F, JF, KF)
58   C
59   C
60   ISTART=0
61   DO 12 J=1,626
62   DO 12 K=1,5
63   12   V(X,J,K)=0.0
64   IB=U
65   DO 7 IA=1,626
66   7    IA=U,0
67   TN=IA*0.01
68   IB=IA-1
69   VF(1)=RH*SIN(TN)
70   VF(3)=HW*COS(TN)
71   CALL MXVECT(AA),VF ^ G,3,3,3,3)
72   DO B J=1,3
73   8    V(XIA,J)=V(G(J))+XC(J)
74   IF(NG) 721,721,722
75   722  CONTINUE
76   DO 9 J=1,NG
77   X1=VX((IA,1)-XAL(1,J)
78   X2=VX((IA,2)-XAL(2,J)
79   X1A=ABS(X1)-XHAL(1,J)*.5
80   X2A=ABS(X2)-XHAL(2,J)*.5
81   IF(XIA)<9.9
82   5    IF(X2A)<9.9
83   6    CONTINUE
84   E8=PI*X1/XHAL(1,J)
85   E9=PI*X2/XHAL(2,J)
86   CE1=COS(E8)
87   CE2=COS(E9)
88   Z1=Z1+HAL(J)*CE1+CE2*CE2
89   9    CONTINUE
90   721  CONTINUE
91   Z1=Z1+AO*(VX(IA,1)-X0)+BD*(VX(IA,2)-Y0)+GO
92   IF(INXY(B100,B101,B100
93   DTA=VX(IA,1)-X0
94   IF(UTA)B101,B102
95   8102 XY=CXA*DTA
96   GO TO 8104
97   8101 XY=0.0
98   8104 CONTINUE
99   Z1=Z1+AY
100  VX(IA,4)=Z1
101  VX(IA,5)=Z1-VX(IA,3)
102  VX1=VX(IA,5)
103  IF(LSTART)1000,13,14
104  13   IF(VX1)>7.16
105  16   ISTART=IA
106  GO TO 7
107  14   CONTINUE
108  1F(VX1)>17.17,7
109  7    CONTINUE
110  17   IC=IB-1START
111  IF(112)1000,4000,9nzu
112  1F(1IC)1000,20,21
113  20   GO TO 4000

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```

114      21    CONTINUE
115      IAA=ISTART-1
116      IF(IAAA)8405,8405,8401
117      CONTINUE
118      I1I=625-16
119      I1I111)8400,8400,8401
120      DO 8402 J=1,5
121      8402 WRITE(6,8403)
122      GO TO 4
123      8403 FORMAT (1H1,46HWHEEL IS COMPLETELY SUBMERGED IN GROUND -TILT)
124      8401 CONTINUE
125      ID=1C+
126      DO 22 J=1,10
127      J1=J+ISTART-1
128      AX(J)=VX(J1,5)
129      AY=AX(ISTART)
130      C
131      C VX(1A,A)=X,Y,Z,GRD,GRD,Z
132      C          1 2 3 4 5
133      C
134      DO 24 K=2,10
135      AZ=AX(K)
136      AT=AY-AZ
137      IF(AT)25,24,24
138      AY=AZ
139      24 CONTINUE
140      D2(I)=AY
141      IST=ISTART-1
142      IBT=IB+
143      RCA=VX(ISTART,5)-VX(IST,5)
144      RBA=-VX(IST,5)/RCA
145      REA=VX(IB,5)-VX(IBT,5)
146      RBB=VX(IB,5)/REA
147      DO 9180 J=1,3
148      BSTAR(I)=VX(IST,J)+RBA*(VX(IST,J)-VX(IST,J))
149      BIB(J)=VX(IB,J)-RBB*(VX(IB,J)-VX(IBT,J))
150      SX=BSTAR(1)-BIB(1)
151      AY=BSTAR(2)-BIB(2)
152      AZ=BSTAR(3)-BIB(3)
153      RIST=IST
154      RIB=IB
155      WS=(RIST+RBA)*0.01
156      WE=(IB+RBB)*.01
157      AL=S*SX+AY+AZ+AZ*AZ
158      AL=SORIAL
159      T1(1)=SX/AL
160      T1(2)=AY/AL
161      T1(3)=AZ/AL
162      WU(1)=RW*SIN(WS)
163      WU(3)=RW*COS(WS)
164      WV(1)=RW*SIN(WE)
165      WV(3)=RW*COS(WE)
166      CALL MAVECT(AA1,WU,V5,3,3,3)
167      CALL MXVECT(AA1,WV,V6,V6,3,3,3)
168      DO 31 J=1,3
169      VAI(J)=.5*(VS(J)+VE(J))
170      CALL MAVECT(VT,VA,VL,3,3,3)

```

```

171      DO 32 J=1,3
172      32      VB(J)=Z(J,1)+VL(J)
173      CALL MXVECT(CT,VB,VBB,J,3,3)
174      CALL MXVECT(B,VB,YAA,3,3,3)
175      DO 931 J=1,3
176      YA(J)=X(J)+YA(J)
177      Z1=0.0
178      S1=0.0
179      S2=0.0
180      IF(NG) 723,723,724
181      724      CONTINUE
182      DO 901 J=1,NG
183      X1=YA(1)-XAL(1,J)
184      X2=YA(2)-XAL(2,J)
185      X1A=ABS(X1)-XHAL(1,J)/2.
186      X2A=ABS(X2)-XHAL(2,J)/2.
187      IF(X1A)902,901,901
188      IF(X2A)903,901,901
189      903      CONTINUE
190      E8=PI*X1/XHAL(1,J)
191      E9=PI*X2/XHAL(2,J)
192      CE1=COS(E8)
193      SE1=SIN(E8)
194      CE2=COS(E9)
195      SE2=SIN(E9)
196      Z1=Z1+HAL(J)*CE1*CE2*CE2*CE2
197      S1=S1-2.0*PI*HAL(J)*CE1*SE1*CE2*CE2/XHAL(1,J)
198      S2=S2-2.0*PI*HAL(J)*CE1*CE2*SE2/XHAL(2,J)
199      901      CONTINUE
200      723      CONTINUE
201      S1=S1+AO
202      S2=S2+BO
203      Z1=Z1+AO*(XC(1))-X0+BO*(XC(2)-Y0)+GO
204      IF(NXY)8106,8105,8106
205      8106      DTA=Y(1)*XC0
206      IF(DTA)8105,8105,8105
207      8107      XY=CY*DTA
208      SE1=CY
209      GO TO 8109
210      8105      XY=0.0
211      SE1=0.0
212      8109      CONTINUE
213      Z1=Z1+XY
214      S1=S1+SE1
215      TS=1.0+SI*SI
216      T4=1.0+52*SI
217      T5=SORT(T5)
218      T4=SORT(T4)
219      SGX=SI/T5
220      CGX=0/T5
221      SGY=SG2/T4
222      CGY=1.0/T4
223      ELN=CGX*CGX+SGX*SGX+CGY*CGY
224      ELNSORT(ELNI)
225      TK(1)=-SGX*CGY/ELN
226      TK(2)=-SGY*CGX/ELN
227      TK(3)= CGX*CGY/ELN

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228      CALL CROSSP(TK,T1,T2)
229      CALL CROSSP(T1,T2,T3)
230      T21=T2(1)*T2(1)+T2(2)*T2(2)
231      T21=SQR(T21)
232      D22=T2(3)/T21
233      T31=T1(1)*T1(1)+T1(2)*T1(2)
234      T31=SQR(T31)
235      D21=T1(3)/T31
236      DO 33 J=1,3
237      33   TVB(UJ)=U(UJ)*VBB(UJ)
238      CALL MAVECT(B,TVB,V1,3,3,3)
239      DO 34 J=1,3
240      G(1,J)=T1(UJ)
241      G(2,J)=T2(UJ)
242      G(3,J)=T3(UJ)
243      CALL MAVECT(G,V1,VTAU,3,3,3)
244      C
245      C (T1,T2,T3)=G(1,J,K)
246      C
247      C VTAU ARE VELOCITY COMPONENTS ALONG (T1,T2,T3)
248      C
249      C
250      C (T1,T2,T3)=H(IF,JF,KB)
251      C
252      CALL MMMLT(G,AA1,H,3,3,3,3)
253      CALL MXTRN(H,HT,3,J,3,3)
254      V11=H(3,1)*VTAU(3)
255      V(2)=H(3,2)*VTAU(3)
256      V(3)=H(3,3)*VTAU(3)
257      DO 7073 J=1,3
258      V(J)=V(J)
259      E1(1,4)=1.
260      E1(2,5)=1.
261      E1(3,6)=1.
262      E1(4,4)=H(1,1)
263      E1(4,5)=H(1,2)
264      E1(4,6)=H(1,3)
265      E1(5,4)=H(2,1)
266      E1(5,5)=H(2,2)
267      E1(5,6)=H(2,3)
268      E1(6,1)=H(3,1)
269      E1(6,2)=H(3,2)
270      E1(6,3)=H(3,3)
271      DT(I)=D2(I)*G(3,3)
272      F1(I)=CS(3,I)*V13)
273      F1(6)=0(I)
274      DO 402 J=1,3
275      402   FQ(J)=(SIA(J,I)-S1A(J,I))*SL(J,I)
276      FQ(3)=FQ(3)+CS(3,I)*V13)
277      NA(1,1)=0
278      NA(2,1)=0
279      NA(3,1)=0
280      E1(1,1)=S1A(1,1)
281      E1(2,2)=S1A(2,1)
282      E1(3,3)=S1A(3,1)
283      DO 510 J=1,6
284      DO 510 K=1,6

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UTMO PTM10D=2•P1 X(J)=1

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285      510      E3(J,K)=E1(J,K)
286          V(1)=1.
287          CALL DGJR(E3,6,6,6,6,5511,J,C,V1)
288          CONTINUE
289          DO 515 K=1,6
290          DO 515 L=1,6
291          E2(K,L5)=E3(K,L5)
292          CALL MAVECT(E2,F1,F2,6,6,6,6)
293          C
294          C CHECK AND SEE IF WE ARE IN NON LINEAR SPRING REGION
295          C IWIN=0 DENOTES WHEEL OFF GROUND
296          C IWIN=1 DENOTES LINEAR REGION
297          C IWIN 2,3 DENOTES NON-LINEAR REGION ENCOUNTERED
298          C
299          C
300          C
301          C          DO 403 J=1,3
302          DR(1)=SL(1,1)-F2(1)
303          DR(2)=SL(2,1)-F2(2)
304          DR(3)=SL(3,1)-F2(3)
305          J1=J+1
306          IWIN(I)=J
307          IF(DR(I))404,404,415
308          NA(1,J1)=1
309          404        GO TO 406
310          405        NA(1,J1)=0
311          406        CONTINUE
312          IF(DR(2))407,407,408
313          NA(2,J1)=1
314          407        GO TO 409
315          408        NA(2,J1)=0
316          409        CONTINUE
317          409        IF(DR(3))410,410,411
318          NA(3,J1)=1
319          410        GO TO 412
320          411        NA(3,J1)=0
321          411        CONTINUE
322          412        CONTINUE
323          MA1=NA(1,J1)-NA(1,J1)
324          MA2=NA(2,J1)-NA(2,J1)
325          MA3=NA(3,J1)-NA(3,J1)
326          IF(MA1)420,415,420
327          IF(MA2)420,416,420
328          IF(MA3)420,417,420
329          417        GO TO 470
330          420        IF(NA(1,J1))1000,430,431
331          430        E1(1,1)=-S1A(1,1)
332          F1(1)=U,U
333          GO TO 432
334          431        E1(1,1)=-S1B(1,1)
335          F1(1)=FQ(1)
336          432        CONTINUE
337          IF(NA(2,J1))1000,433,434
338          E1(2,2)=-S1A(2,1)
339          F1(2)=0,0
340          GO TO 435
341          434        E1(2,2)=-S1B(2,1)

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342      F1(2)=FQ(2)
343      CONTINUE
344      422  IF(NA(3,J1))1000,436,437
345      436  E1(3,J)=SIA(3,J)
346      F1(3)=CS(3,J)*V(3)
347      GO TO 438
347      437  E1(3,J)=S1B(3,J)
348      F1(3)=FQ(3)
349      438  CONTINUE
350
351      V(1)=1.
352      DO 513 K=1,6
353      513  DO 513 L=1,6
354      513  E3(K,L5)=E1(K,L5)
355      CALL DGJR(E3,6,6,6,SS514,JC,V1)
356      514  CONTINUE
357      DO 521 K=1,6
358      521  DO 521 L5=1,6
359      521  E2(K,L5)=E3(K,L5)
360      CALL MVECT(E2,F1,F2,6,6,6,6)
361      403  CONTINUE
362      470  CONTINUE
363      LI=1W1N(1)
364      PNF(3,1)=F2(4)*H(3,1)+F2(5)*H(3,2)+F2(6)*H(3,3)
365      IF(PNF(3,1))9190,9190,9191
366      9190  PNF(3,1)=0.0
367      GO TO 4000
368      9191  CONTINUE
369      VNR(1)=VTAU(3)
370      C1=ABS(VTAU(2))
371      IF(C1.LT.VSE) GO TO 180
372      PNF(2,1)=-SIGN(1.0,VTAU(2))*SF•PNF(3,1)
373      GO TO 190
374      180  PNF(2,1)=-SIGN(1.0,VTAU(2))*ABS(VTAU(2))*SF•PNF(3,1)/VSE
375      190  CONTINUE
376      IF(NROL(1))200,210,200
377      210  IF(NBRAK(1))220,230,220
378      230  IF(NTORQ(1))240,250,240
379      250  PNFI(1)=0.0
380      GO TO 30
381      200  VDE=ABS(VTAU(1))
382      IF(VDE)490,490,491
383      490  PNFI(1)=0.0
384      GO TO 30
385      491  PNF(1,1)=-SIGN(1.0,VTAU(1))*RF•PNF(3,1)
386      GO TO 30
387      220  VDE=ABS(VTAU(1))
388      1F(VDE)492,492,493
389      492  PNFI(1,1)=0.0
390      GO TO 30
391      493  VDE=BDF•PNF(3,1)
392      VDF=CONS-VDE
393      IF(VDF)494,494,495
394      494  PNF(1,1)=-SIGN(1.0,VTAU(1))*CONS
395      GO TO 30
396      495  PNF(1,1)=-SIGN(1.0,VTAU(1))*VDE
397      GO TO 30
398      240  AVI=ABS(VTAU(1))

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399      FF=TF•PNF(3,1)
400      AV=VMAX-AVI
401      IF(AVI>280,280,201
402      AV2=0.0
403      GO TO 205
404      2U1      AV=AVI-VMIN
405      IF(AVI>202,202,203
406      AV1=VMIN
407      2U3      CONTINUE
408      CALL FTORG(AVI,AV2,CVT,NP,MP)
409      2U5      CONTINUE
410      FT=AV2/RW
411      AFT=AFT-FF
412      IF(AFT>26,26,27
413      PNF1,1)=FT•UNIT
414      GO TO 30
415      27      PNF1,1)=FF•UNIT
416      30      CONTINUE
417      CALL MXMLT(G,B,GB,3,3,3,3)
418      CALL MATRN(GB,GBT,3,3,3,3)
419      DO 182 J=1,3
420      PNR(J)=PNF(J,1)
421      CALL MXVECT(GBT,PNR,PNJ,3,3,3)
422      DO 181 J=1,3
423      DO 181 K=1,3
424      181      AN(J,K,1)=G(J,K)
425      DO 9001 J=1,6
426      9001      FDISP(J)=F2(J)
427      CALL MXVECT(AAA,FDISP,BDISP,3,6,3,6)
428      DO 9002 J=1,6
429      9002      BDI(J,1)=BDIS(J)
430      DII,J,1)=1.0
431      D12,2)=1.0
432      D13,3)=1.0
433      D14,2)=VB(3)
434      D14,3)=VB(2)
435      D15,1)=VB(3)
436      D15,3)=VB(1)
437      D16,1)=VB(2)
438      D16,2)=VB(1)
439      CALL MXVECT(D,PNJ,PNJ,6,3,6,3)
440      DO 195 J=1,3
441      195      PN6(J,1)=PNJ(J)
442      DO 320 J=1,6
443      320      PWF(J)=PWF(J)+PNJ(J)
444      GO TO 4
445      4000      L2(I)=1
446      VNOR(I)=0.0
447      IWIN(I)=0
448      4      CONTINUE
449      1000     CONTINUE
450      RETURN
451      END

```

UEMO PERIOD=20 PI X(3)=1

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24

OVER=SK3190.GRAV  
1 SUBROUTINE GRAV(B,XM,GM,GH)  
2 DIMENSION B(3,3),XM(6,6),GR(6)  
3 DIMENSION VT(6)  
4 VT(1)=B(3,1) \*GH  
5 VT(2)=B(3,2) \*GH  
6 VT(3)=B(3,3) \*GH  
7 CALL MXVECT(XM,VT,GR,6,6,6)  
8 RETURN  
9 END

3 PRT,S SK3190.TURVEL

UEMO PERIOD=2\*PI X(3)=1

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```
1  OVER•SK319U•TORVEL
2      SUBROUTINE TORVEL(A,Y,A,NP,MP,B,JC,VI)
3      DOUBLE PRECISION D,VI
4      DIMENSION B(MP,MP),X(MP),Y(MP),A(MP),JC(MP),VI(2)
5      DIMENSION D(MP,MP)
6      DIMENSION C(8,8),E(8,8)
7      DO 1 L=1,NP
8      B(L,L)=1.0
9      DO 2 K=2,NP
10     K1=K-1
11     2    B(L,K)=X(L)*K1
12     CONTINUE
13     VI(1)=1.0
14     DO 6 I=1,NP
15     DO 6 J=1,NP
16     D(I,J)=B(I,J)
17     C(I,J)=B(I,J)
18     6    CALL DGJR(D,MP,MP,NP,NP,S3,JC,VI)
19     CONTINUE
20     DO 8 I=1,NP
21     DO 8 J=1,NP
22     B(I,J)=D(I,J)
23     CALL MAVECT(B,Y,A,NP,NP,MP,MP)
24     CALL MXMLTIC(B,E,NP,NP,NP,MP,MP)
25     RETURN
END
```

3 PRT.S

SK3190•MASS

## TOWER-SK3190-MASS

```

1      SUBROUTINE MASS(Y,L2,XM,Z, AM)
2      DIMENSION Y(10),L2(4),XM(6,6),Z(3,4)
3      C   L2 IS *WHEEL INDICATOR L2(1)=U,1 IMPLIES WHEEL(1) ON/OFF GROUND
4      C   XM IS 6X6 MASS MATRIX, Z IS 3X4 MATRIX OF WHEEL HUB COORDINATES
5      C   FOR WHEEL EXTENDED
6      C   Y ARE SPRUNG MASS PROPERTIES
7      C
8      XM(1,1)=Y(3)-IY(4)=IZZ,S=MX,6=HY,7=HZ,8=IXY,9=IXZ,10=IYZ
9      XM(4,5)=-Y(8)
10     XM(4,6)=-Y(9)
11     XM(5,4)=-Y(8)
12     XM(5,6)=-Y(10)
13     XM(6,4)=-Y(9)
14     XM(6,5)=-Y(10)
15     XM(1,1)=Y(1)
16     XM(2,2)=Y(1)
17     XM(3,3)=Y(1)
18     XM(4,4)=Y(2)
19     XM(5,5)=Y(3)
20     XM(6,6)=Y(4)
21     XM(1,5)=Y(7)
22     XM(1,6)=Y(6)*(-1.)
23     XM(2,4)=Y(7)*(-1.)
24     XM(2,6)=Y(5)
25     XM(3,4)=Y(6)
26     XM(3,5)=Y(5)*(-1.)
27     XM(4,2)=Y(7)*(-1.)
28     XM(4,3)=Y(6)
29     XM(5,1)=Y(7)
30     XM(5,3)=Y(5)*(-1.)
31     XM(6,1)=Y(6)*(-1.)
32     XM(6,2)=Y(5)
33     DO 1 I=1,4
34     IF (L2(I)) 1000,1,2
35     XM(1,1)=XM(1,1)*WM
36     XM(2,2)=XM(2,2)*WM
37     XM(3,3)=XM(3,3)*WM
38     XM(4,4)=XM(4,4)*(Z(2,2,1)**2+Z(3,1)**2)*WM
39     XM(5,5)=XM(5,5)*(Z(1,1,1)**2+Z(3,1)**2)*WM
40     XM(6,6)=XM(6,6)*(Z(1,1,1)**2+Z(2,1)**2)*WM
41     XM(1,5)=XM(1,5)*Z(3,1)*WM
42     XM(2,4)=XM(2,4)*Z(2,1)*WM
43     XM(2,6)=XM(2,6)*Z(1,1)*WM
44     XM(3,4)=XM(3,4)*Z(2,1)*WM
45     XM(3,5)=XM(3,5)*Z(1,1)*WM
46     XM(4,2)=XM(2,4)
47     XM(4,3)=XM(3,4)
48     XM(5,1)=XM(1,5)
49     XM(5,3)=XM(3,5)
50     XM(6,1)=XM(1,6)
51     XM(6,2)=XM(2,6)
52     XM(4,5)=XM(4,5)-Z(1,1)*Z(2,1)*WM
53     XM(4,6)=XM(4,6)-Z(1,1)*Z(3,1)*WM
54     XM(5,6)=XM(5,6)-Z(2,1)*Z(3,1)*WM
55     XM(5,4)=XM(4,5)
56     XM(6,4)=XM(4,6)

```

UENO PERIOD=2@P1 A(3)=1

57 XM(6,5)=XM(5,6)  
58 1 CONTINUE  
59 1000 CONTINUE  
60 RETURN  
61 END

9 PRT,5 SK3190.FORIN

DATE 04017U

PAGE

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DEMO PERIOD=20PI X(3)=1

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```
10VER*SKJ190.FORIN      SUBROUTINE FORIN(C,XM,U,FINE)
11
12      REAL MEGA
13      DIMENSION C(3,3),XM(6,6),U(6),V(6),MEGA(6,6),FINE(6)
14      CALL MXVECT(XM,U,V,6,6,6)
15      DO 1 I=1,3
16      11=I+3
17      DO 1 J=1,3
18      J1=J+3
19      MEGA(I,J)=C(I,J)
20      10      MEGA(I,J1)=C(I,J)
21      CALL MXVECT(MEGA,V,FINE,6,6,6)
22      RETURN
23      END
```

3 PRT.S SKJ190.DICOS

```

1 20VER*SK3190.DICUS          SUBROUTINE DICOS( U , D )
2           DIMENSION U(3),  

3           X1=U(1)*2+U(3)*2
4           X2=U(1)*2+U(3)*2
5           X3=U(1)*2+U(2)*2
6           UMA=U(1)*U(2)
7           UMB=U(1)*U(3)
8           UMC=U(2)*U(3)
9           S=U(1)*2+U(2)*2+U(3)*2
10          V= SQRT(S)
11          IF(V.LE.1.E-07)GO TO 1
12          EN=SIN(V)/V
13          GO TO 2
14          EN=1.
15          2  CONTINUE
16          IF(V.LE.1.E-03)GO TO 3
17          EM=(1.-COS(V))/S
18          GO TO 4
19          EM=.5
20          4  CONTINUE
21          F(1,1)=1.0*X1*EM
22          F(1,2)=-U(3)*EN+UMA*EM
23          F(1,3)=U(2)*EN+UMB*EM
24          F(2,1)=U(3)*EN+UMA*EM
25          F(2,2)=1.0-X2*EM
26          F(2,3)=-U(1)*EN+UMC*EM
27          F(3,1)=-U(2)*EN+UMB*EM
28          F(3,2)=U(1)*EN+UMC*EM
29          F(3,3)=1.0-X3*EM
30          DO 7 I=1,3
31          DO 7 J=1,3
32          A(I,J)=0.0
33          DO 7 K=1,3
34          7  A(I,J)=A(I,J)+D(I,K)*F(K,J)
35          DO 8 I=1,3
36          DO 8 J=1,3
37          8  D(I,J)=A(I,J)
38          6  RETURN
39          END

```

R0VER•SKJ19U.0R

```

1      SUBROUTINE QR(N,A,B,E,X,SN,CS,C,L)
2      C   THIS SUBROUTINE FINDS THE EIGENVALUES AND EIGENVECTORS OF A
3      C   SYMMETRIC TRIDIAGONAL MATRIX. N IS THE DIMENSION, A(1) . . . A(N) THE
4      C   DIAGONAL, B(2) . . . B(N) THE OFF-DIAGONAL, E(1) . . . E(N) THE EIGENVALUES,
5      C   X(1,K) . . . X(N,K) IS THE EIGENVECTOR CORRESPONDING TO E(K), AND SN,
6      C   CS, C ARE ONE DIMENSIONAL WORKING ARRAYS.
7      DIMENSION A(L),B(L),E(L),X(L,N),SN(L),CS(L),C(L)
8      REAL NORM, MU,LAM
9      C   SET THE X ARRAY EQUAL TO THE NXN IDENTITY
10     DO 200 I=1,N
11        DO 201 J=1,N
12          X(I,J)=0.
13        201 X(J,I)=0.
14        200 X(I,I)=1.
15        B(1)=0.0
16        NORM = ABS(B(N))+ABS(A(N))
17        NI=N-1
18        DO 10 I=1,N'
19          SUM=ABS(A(I))+ABS(B(I))+ABS(B(I+1))
20          IF (SUM .GT. NORM) NORM=SUM
21          CONTINUE
22          EPS=NORM * (1.0-E-B)
23          MU=0.
24          M=N
25          15  IF (M.LE.0) GO TO 500
26          C   CHECK FOR POSSIBLE DECOUPLING OF THE MATRIX
27          20  IF (ABS(B(M)) .GT. EPS) GO TO 40
28          E(M)=A(M)
29          M=M-1
30          GO TO 15
31          M=M-1
32          K=M
33          41  IF (ABS(B(K)) .LE. EPS) GO TO 42
34          K=K-1
35          GU TO 41
36          C   DETERMINE THE SHIFT OF ORIGIN
37          42  B= B(M)**2
38          A=SQRT((A(M))-A(M))**2+4.*EPS
39          T=A(M)*A(M)-B*B
40          A=A(M)+A(M)
41          FACT=1.0
42          IF (A .LT. 0.1 FACT=.1.0
43          LAM=0.5*(A+FACT*A)
44          T=T/LAM
45          IF (ABS(T-MU)=0.5*ABS(T)) T=70.,80.,80
46          MU=T
47          LAM=T
48          GO TO 90
49          IF (ABS(LAM-MU)=0.5*ABS(LAM)) 81,82,82
50          MU=LAM
51          GO TO 90
52          MU=T
53          LAM=0.
54          90  A(K)=A(K)-LAM
55          BETA=B(K+1)
56          C   DO THE TRANSFORMATION ON THE LEFT

```

```

57      DO 110 J=K,M
58      A0=A(JJ)
59      A1=A(J+1)-LAM
60      BU=B(J+1)
61      T=SQR(A0+Z*RETA*Z)
62      COSE=A0/T
63      CS(JJ)=COS(E)
64      SINE=BETA/T
65      SN(JJ)=SINE
66      A(JJ)=COS(E)*A0*SINE*BETA
67      A(J+1)=-SINE*BO+COS(E)*A1
68      B(J+1)=COS(E)*BO+SINE*A1
69      BETA=B(J+2)
70      B(J+2)=COS(E)*BETA
71      C(J+1)=SINE*BETA
72      CONTINUE
73      110  DO THE TRANSFORMATION ON THE RIGHT
74      B(K)=0.
75      CIK=1.0.
76      DO 110 J=K,M
77      SINE=SN(JJ)
78      COSE=CS(JJ)
79      ADA=A(J)
80      BU=B(J+1)
81      B(J)=BIJ)*COS(E)+C1J )*SINE
82      A(J)=AO*COS(E)+BO*SINE+LAM
83      B(J+1)=AD*SINE+BO*COS(E
84      A(J+1)=A(J+1)*COS(E
85      C      APPLY THE TRANSFORMATIONS TO THE X MATRIX
86      DO 120 I=1,N
87      X0=X(I,J)
88      X1=X(I,J+1)
89      X11=X(I,J)*X0*COS(E)+X1*SINE
90      X111=X(I,J+1)*X0*SINE+X1*COS(E
91      120  CONTINUE
92      CONTINUE
93      AIM=A(M)+LAM
94      GO TO 15
95      RETURN
96      END

```

DEMO PERIOD=20PI X(3)=1

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ROVER•SK3190•TRANSF

```
1      SUBROUTINE TRANSF(N,A,X,C,M)
2      C      THIS SUBROUTINE TRANSFORMS THE EIGENVECTORS OF A TRIDIAGONAL
3      C      MATRIX INTO THE EIGENVECTORS OF THE ORIGINAL MATRIX.
4      C      A IS THE MATRIX WHICH WAS USED AS INPUT TO TRIDMX, AND
5      C      X IS THE MATRIX OF EIGENVECTORS
6      C      DIMENSION A(M,M),X(M,M),C(M,M)
7      N2=N-2
8      DO 102 K1=1,N2
9      K=N-K1
10     K2=K-1
11     DO 103 J=1,N
12     SUM=0
13     DO 104 I=K,N
14     SUM=SUM+A(I,K2)*X(I,J)
15     C(J)=2.*SUM
16     DO 105 I=K,N
17     DO 105 J=1,N
18     X(I,J)=X(I,J)-A(I,K2)*C(J)
19     CONTINUE
20     RETURN
21     END
```

6 PRT,S SK3190.DOTVEC

UENIO PERTUZ-ZPFI X(3)=1

```
1  COVER•SK3190•NOTVEC
2      SUBROUTINE NOTVEC(V,W,A)
3      DIMENSION V(3),W(3)
4      A=0.0
5      DO 1 J=1,3
6      A=A+V(J)*W(J)
7      RETURN
     END
```

6 PRT,S SK3190•FTORQ

PAGE

171431Z

PT100020P1 A(3)=1

ROVER•SK3190•FIG09  
1 SUBROUTINE FIG09(AV1,AV2,CVT,...,4P)  
2 DIMENSION CVT(MP)  
3 AV2=CVT(1)  
4 DO 1 I=2,NP  
5 1=I-1  
6 1 AV2=AV2+CVT(I)\*(AV1•••)  
7 RETURN  
8 END

R PRT,S SK3190•MVECT

1.

2. 3. 4. 5. 6. 7. 8.

9. 10. 11. 12. 13. 14. 15.

16. 17. 18. 19. 20. 21. 22.

```
1      SUBROUTINE AXVECT(A,V,W,N,M)
2      DIMENSION A(M,M),V(M),W(M)
3      DO 1 I=1,N
4      W(I)=U(1)
5      DO 1 J=1,M
6      W(I)=W(I)+A(I,J)*V(J)
7      RETURN
8      END
```

16 PRT,S SK3190.CROSSP

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```
1      ROVER•SKJ190•CROSSP
2      SUBROUTINE CROSSP (V1,V2,V3)
3      DIMENSION V1(3),V2(3),V3(3)
4      A=V1(2)•V2(3)-V1(3)•V2(2)
5      B=V1(3)•V2(1)-V1(1)•V2(2)
6      C=V1(1)•V2(2)-V1(2)•V2(1)
7      D=A•A+B•B+C•C
8      D=SQRT(D)
9      V3(1)=A/D
10     V3(2)=B/D
11     V3(3)=C/D
12     RETURN
END
```

DEMO PERIOD=20PI A(3)=1

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w XQT SKJ190.ABS  
N50=1.5A=4\*1..SB4\*30..S5=4\*10..4M=1..GM=1..U=10..  
Y=4..100000..100000..200000..  
Z=100..100..-2..100..-100..-100..-100..-100..-100..-100..-2..  
NINT=200..DELTIM=15707963..IPMT=10..GO=-10..RN=10..  
SEND

SPRUNG MASS MATRIX (NO WHEELS)

4.00000000+00	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	4.00000000+00	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	4.00000000+00	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	1.00000000+05	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	1.00000000+05	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	2.00000000+05
XBAR= 0.00000000	YBAR= 0.00000000	ZBAR= 0.00000000			

MOMENT OF INERTIA TENSOR ABOUT CG

Ixx= 1.00000000+05 Iyy= 1.00000000+05 Izx= 2.00000000+05 Ixy= 0.00000000 Izx= 0.00000000 Iyz= 0.00000000

ROTATION VECTOR & PRINCIPAL INERTIAS

PRINCIPAL INERTIA= 1.00000000+05	1.00000000+00	0.00000000	0.00000000
PRINCIPAL INERTIA= 1.00000000+05	0.00000000	1.00000000+00	0.00000000
PRINCIPAL INERTIA= 2.00000000+05	0.00000000	0.00000000	1.00000000+00

CG RELATIVE TO WHEEL CENTER ORIGIN AT GROUND AT TIME=0 (BODY COORDINATES) ASSUMING WHEELS HAVE BEEN TRIMMED  
X= 0.000000 Y= 0.000000 Z= 1.00000000+01

TIME = 0.000000	SECONDS	0 TIME INTERVALS	ISUB INTERVALS
BODY TRANSLATIONAL AND ANGULAR VELOCITIES			
1.000000+01 U.000000 U.000000	0.000000	0.000000	0.000000
X,Y,Z TRAJECTORY			
0.000000 0.000000 0.000000	0.000000	0.000000	0.000000
DIRECTION COSINE MATRIX			
1.000000+01 0.000000 0.000000	0.000000	0.000000	0.000000

DEMC PERIOD=20PI X(13)=1

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WHEEL-GROUND FORCES 1-BODY J-BODY  
0.0000000 1.0000000 0.0000000 1.0000000  
0.0000000 0.0000000 1.0000000 0.0000000

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-3.9737293-08 3.0000007 9.9998721-01 0.0000000

WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES 1-BODY J-BODY K-BODY  
-3.9737294-08 0.0000000 1.0000000 1.0000000  
-3.9737294-08 0.0000000 1.0000000 1.0000000  
-3.9737294-08 0.0000000 1.0000000 1.0000000  
-3.9737294-08 0.0000000 1.0000000 1.0000000

STEERING ANGLES DEGREES 0.0000000 C.0000000 D.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES 0.0000000 0.0000000 0.0000000 0.0000000

GRAVITY FORCES 0.0000000 0.0000000 -4.0000000+00 0.0000000 0.0000000

WHEEL FORCES -1.589492-07 0.0000000 7.999949+00 0.0000000 -2.079010-04 0.0000000

TIME = 1.5707963+00 SECONDS 10 TIME INTERVALS 15UB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 1.0009209+00 0.0000000 -9.99968404-10 0.0000000

X,Y,Z TRAJECTORY  
1.5707963+01 0.0000000 9.9831656-01

DIRECTION COSINE MATRIX  
1.0000000+00 0.0000000 -1.0107335-09  
0.0000000 1.0000000+00 0.0000000  
1.0107335-09 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-2.6370888-08 0.0000000 1.6706288-03 0.0000000 -3.3187866-07 0.0000000

WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES 1-BODY J-BODY K-BODY  
-2.6360758-08 0.0000000 1.0016706+03  
-2.6360758-08 0.0000000 1.0016706+03  
-2.6360761-08 0.0000000 1.0016707+03  
-2.6360761-08 0.0000000 1.0016707+03

STEERING ANGLES DEGREES 0.0000000 C.0000000 D.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES 4.00241e-07 0.0000000 -3.0000000 0.0000000

GRAVITY FORCES -4.14253e-07 0.0000000 -4.0000000 0.0000000

DEMO PERIOD=20P1 X(1)=1

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WHEEL FORCES -1.054430-07 0.000000 4.000663+00 0.000000 -3.318787-04 0.000000

TIME = 3.1415926+00 SECUNDUS 20 TIME INTERVALS 1SUB INTERVALS  
 BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.000000 3.217197-03 0.0000000 -5.9012552-10 0.0000000

X,Y,Z TRAJECTORY  
 3.1415925+01 0.000000 1.9997789+00  
 DIRECTION COSINE MATRIX

1.0000000+01	0.0000000	-2.7871650-09
0.0000000	1.0000000+01	0.0000000
2.7871650-09	0.0000000	1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -2.7652665-09 0.0000000 -9.999999-01 0.0000000 1.4603483-17 0.0000000

WHEEL INDICATOR L2. 1 1 1

WHEEL-GROUND FORCES	I-BODY	J-BODY	K-BODY
0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES R.353419-12 0.000000 -2.596552-06 0.000000 0.0000000

GRAVITY FORCES -1.226353-08 0.000000 -4.400000+00 0.000000 2.229732-09 0.0000000

WHEEL FORCES 0.000000 0.000000 0.000000 0.000000 0.000000 0.0000000

TIME = 4.71238869+00 SECUNDUS 30 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.000000 -1.0007207+00 0.0000000 -1.8126525-11 0.0000000X,Y,Z TRAJECTORY  
 4.7123885+01 0.000000 1.0048656+00

DIRECTION COSINE MATRIX	1.0000000+00	0.0000000	-7.6244259-09
	0.0000000	1.0000000+01	0.0000000
	2.6244259-09	0.0000000	1.0000000+00

DEMO PERIOD=20PI X(3)=1

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BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -2.73U940-08 0.000000 -4.6734167-03 0.000000 1.1825361-U7 0.000000

WHEEL INDICATOR L2, 0 0 0 0

WHEEL-GROUND FORCES 1-BODY J-ROUY K-BODY  
 -2.4667373-08 0.000000 9.9512135-01  
 -2.4667373-08 0.000000 9.9512135-01  
 -2.4667377-08 0.000000 9.9512183-01  
 -2.4667377-08 0.000000 9.9512183-01

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES -7.255835-11 0.000000 -7.250610-10 0.000000 0.000000

GRAVITY FORCES -1.049770-08 0.000000 -4.000000+00 0.000000 0.000000

WHEEL FORCES -9.366950-08 0.000000 3.980486+00 0.000000 1.182556-U4 0.000000

TIME = 6.283185200 SECONDS 40 TIME INTERVALS 15 SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.000000J -6.4333826-03 0.000000 6.2203079-10 0.000000

X,Y,Z TRAJECTORY  
 6.2831845+01 0.000000 4.00331387-04

DIRECTION COSINE MATRIX  
 1.0000000+00 0.000000 -1.9305768-09  
 0.0000000 1.0000000+00 0.0000000  
 1.9305768-09 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -3.7799084-08 0.000000 9.9958685-01 0.000000 -1.4305115-U9 0.000000

WHEEL INDICATOR L2, 0 0 0 0

WHEEL-GROUND FORCES 1-BODY J-BODY K-BODY  
 -3.5872511-08 0.000000 1.9975067+00  
 -3.5872511-08 0.000000 1.9975067+00  
 -3.5872508-08 0.000000 1.9975070+00  
 -3.5872508-08 0.000000 1.9975070+00

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES 1.600705-11 0.000000 2.486123-U8 0.000000 0.000000

GRAVITY FORCES -7.722307-09 0.000000 -4.000000+00 0.000000 0.000000

WHEEL FORCES -1.434910-U7 0.000000 7.994347+00 0.000000 1.143211-U4 0.000000

DEMO PERIOD=20P1 X(3)=1

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TIME = 7.8539814+00 SECONUS 50 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 1.0005102+00 0.0000000 1.0061107-10 0.0000000

X,Y,Z TRAJECTORY  
7.8539805+01 0.0000000 9.9189109-01

DIRECTION COSINE MATRIX

1.0000000+00 0.0000000 -1.3915614-09  
0.0000000 1.0000000+00 0.0000000  
1.3915614-09 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.7635384-08 0.0000000 x.0760691-03 0.0000000 -2.0217695-U9 0.0000000

WHEEL INDICATOR L2, 0 0 0

\*WHEEL-GROUND FORCES I-BODY

-2.6063117-08 0.0000000 1.0080960+00  
-2.6063117-08 0.0000000 1.0080960+00  
-2.6063120-08 0.0000000 1.0080962+00  
-2.6063120-08 0.0000000 1.0080962+00

STEERING ANGLES DEGREES 0.000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -7.228161-10 0.000000 7.224475-U9 0.000000 0.000000

GRAVITY FORCES -5.5662446-09 0.000000 -4.0000000+00 0.000000 0.000000

\*WHEEL FORCES -1.042525-07 0.000000 4.032364+00 0.000000 -2.021790-04 0.000000

TIME = 9.4247777+00 SECONDS 60 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 9.6448436-03 0.0000000 0.6051373-10 0.0000000

X,Y,Z TRAJECTORY  
9.4247766+01 0.0000000 1.9993577+00

DIRECTION COSINE MATRIX

1.0000000+00 0.0000000 -5.3479517-10  
0.0000000 1.0000000+00 0.0000000  
5.3479517-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-6.6024549-10 0.0000000 -9.9971117-01 0.0000000 -3.33902422-11 0.0000000

DEMO PERIOD=20P1 X(3)=1

WHEEL INDICATOR L2. 0 0 0 0

WHEEL-GROUND FORCES I-BODY  
-3.01715343-1U 0.0000000 J-BODY  
-3.01715343-1U 0.0000000 K-BODY  
-3.01714819-10 0.0000000 2.0884410-04  
-3.01714819-10 0.0000000 2.0884410-04  
-3.01714819-10 0.0000000 2.0884410-04

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000  
NON LINEAR INERTIA FORCES BODY AXES -3.319808-11 0.000000 3.442055-U8 0.000000 0.000000  
GRAVITY FORCES -2.0139181-09 0.000000 -4.000000+00 0.000000 0.000000  
WHEEL FORCES -1.0268603-09 0.000000 1.015376-03 0.000000 -3.0339024-06 0.000000

TIME = 1.0995574+01 SECONDS 70 TIME INTERVALS 15UB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.000000 -1.0002894+00 0.000000 4.01709323-10 0.0000000

X,Y,Z TRAJECTORY

1.0995573+02 0.000000 1.00112820+00

DIRECTION COSINE MATRIX

1.0000000+00 0.000000 7.3638313-10  
0.0000000 1.0000000+00 0.0000000  
-7.3638313-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-2.6760619-08 0.000000 -1.1294797-02 0.000000 3.07288665-U9 0.000000

WHEEL INDICATOR L2. 0 0 0 0

WHEEL-GROUND FORCES I-BODY  
-2.07914216-08 0.0000000 J-BODY  
-2.07914216-08 0.0000000 K-BODY  
-2.07914215-08 0.0000000 9.0870527-01  
-2.07914215-08 0.0000000 9.0870515-01

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000  
NON LINEAR INERTIA FORCES BODY AXES 1.0668856-09 0.000000 1.0668373-U8 0.000000 0.000000  
GRAVITY FORCES 2.0945533-04 0.000000 -4.000000+00 0.000000 0.000000  
WHEEL FORCES -1.0116569-07 0.000000 3.0954921+00 0.000000 3.0728867-U4 0.000000

DEMO PERIOD 2001 X(3)=.

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TIME = 1.2566370+01 SECONDS 90 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 -1.295057-02 0.0000000 -1.0571456-10 0.0000000

X,Y,Z TRAJECTORY  
1.2566369+02 0.0000000 0.4194460-04

DIRECTION COSINE MATRIX

1.0000000+00 0.0000000 1.3076636-09  
0.0000000 1.0000000+01 0.0000000  
-1.3076636-04 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-4.1035860-08 0.0000000 7.9914536-01

\*WHEEL INDICATOR L2. 0 0 0

\*WHEEL-GROUND FORCES I-BODY

-4.2342187-0d 0.0000000 1.0000000  
-4.2342187-0d 0.0000000 1.0000000  
-4.2342183-08 0.0000000 1.0000000  
-4.2342183-08 0.0000000 1.0000000

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -5.436072-12 0.0000000 -4.226742-U+ 0.0000000 0.0000000

GRAVITY FORCES 5.230655-09 0.0000000 -4.0000000+U 0.0000000 0.0000000

\*WHEEL FORCES -1.693697-07 0.0000000 7.99681+U 0.0000000 -2.0727509+04 0.0000000

TIME = 1.4137167+01 SECONDS 90 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 1.0000583+00 0.0000000 -2.0509080-U+ 0.0000000

X,Y,Z TRAJECTORY  
1.4137164+02 0.0000000 9.8547737-01

DIRECTION COSINE MATRIX

1.0000000+00 0.0000000 -6.7198922-10  
0.0000000 1.0000000+01 0.0000000  
6.7198922-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.5497342-08 0.0000000 1.4509812-U2 0.0000000 -3.35943-U+10 0.0000000

\*WHEEL INDICATOR L2. 0 0 0

\*WHEEL-GROUND FORCES I-BODY

DEMO PERIOD=2\*P1 X(3)=1

-2.6876378-1L	0.0000000	0.0000000	1.014509H+00
-2.6876378-0L	0.0020000	0.0020000	1.0145098+00
-2.6876382-0L	0.0000000	1.0145099+00	1.0145099+00
-2.6876382-0L	0.0000000	1.0145099+00	1.0145099+00

STEERING ANGLES DEGREES	0.0000100	0.0000000	0.0000000	0.0000000			
NON LINEAR INERTIA FORCES	BODY AXES	8.204110-09	0.0000001	-8.203632-U8	0.000000	0.000000	
GRAVITY FORCES		-2.687957-09	0.000000	-4.0000000+00	0.000000	0.000000	
WHEEL FORCES		-1.075055-07	0.000000	4.058039+00	0.000000	-5.435944-05	0.000000

TIME = 1.5707963+01 SECONDS 100 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES	1.6072748-U2	0.0000000	-1.7778096-1U	0.0000000
1.0000000+01	0.0000000			

X,Y,Z TRAJECTORY	1.5707959+02	0.0000007	1.9988963+00	
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DIRECTION COSINE MATRIX				
1.0000000+00	0.0000000	-2.0335988-09		
0.0000000	1.0000000+00	0.0000000		
2.0335988-09	0.0000000	1.0000000+00		

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS	-9.9890907-01	0.0000000	6.7384713-1U	0.0000000
-2.9509970-09	0.0000000			

WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES	1-BODY	J-BODY	K-BODY	
-9.2019529-1U	0.0000000	1.0907650-03	1.0907650-03	
-9.2019529-1U	0.0000000	1.0911226-03	1.0911226-03	
-9.2031599-1U	0.0000000	1.0911226-03	1.0911226-03	
-9.2031599-1U	0.0000000			

STEERING ANGLES DEGREES	0.0000000	0.0000000	0.0000000	0.0000000			
NON LINEAR INERTIA FORCES	BODY AXES	1.142971-11	0.0000000	-7.111238-U7	0.000000	0.000000	
GRAVITY FORCES		-9.134395-09	0.0000000	-4.0000000+00	0.000000	0.000000	
WHEEL FORCES		-3.681023-09	0.0000000	4.363775-04	0.000000	6.738491-05	0.000000

TIME = 1.7278759+01 SECONDS 110 TIME INTERVALS 1SUB INTERVALS

UEMO PERIOD=20PI A(3)=1

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BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.0000000 -9.9981669-01 0.0000000 1.4720231-U9 0.0000000

X,Y,Z TRAJECTORY  
 1.7278754+02 0.0000000 1.0177107+00

DIRECTION COSINE MATRIX  
 1.0000000+01 0.0000000 -1.1933395-09  
 0.0000000 1.0000000+01 0.0000000  
 1.1933395-09 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -2.5243086-08 0.0000000 -1.7723441-02 0.0000000 2.7179718-U9 0.0000000

\*WHEEL INDICATOR L2. 0 U O O

AHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
 -2.5921421-08 0.0000000 9.8227643-01  
 -2.5921421-08 0.0000000 9.8227643-01  
 -2.5921421-08 0.0000000 9.8227667-01  
 -2.5921421-08 0.0000000 9.8227667-01

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NUN LINEAR INERTIA FORCES BODY AXES 7.4886721-U9 0.0000000 7.4886093-U9 0.0000000 0.0000000

GRAVITY FORCES 1.0000000+01 0.0000000 -4.773358-U9 0.0000000 -4.0000000+01 0.0000000 0.0000000

\*WHEEL FORCES -1.036857-U7 0.0000000 3.929106+00 0.0000000 2.717972-U4 0.0000000

TIME = 1.88449555+01 SECUNDUS 120 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.0000000 -1.9289028-U2 0.0000000 2.4577521-U9 0.0000000

X,Y,Z TRAJECTORY  
 1.0849549+02 0.0000000 1.3245775-U3

DIRECTION COSINE MATRIX  
 1.0000000+00 0.0000000 2.8214946-09  
 0.0000000 1.0000000+01 0.0000000  
 -2.8214946-U9 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -4.2492949-U8 0.0000000 9.9866264-U1 0.0000000 -3.5858154-U9 0.0000000

\*WHEEL INDICATOR L2. 0 U O O

AHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
 -4.5361860-U8 0.0000000 1.9986629+01  
 -4.5361860-U8 0.0000000 1.9986629+01  
 -4.5361843-U8 0.0000000 1.9986623+01

DEMO PERIOD=20P1 #131#1 -4.5361843-08 0.0000000 1.9786623-00

STEERING ANGLES DEGREES	0.000000	0.000000	0.000000	0.000000	0.000000
NON LINEAR INERTIA FORCES BODY AXES	1.496306-10	0.000000	9.31008-08	0.000000	0.000000
GRAVITY FORCES	1.028598-08	0.000000	-4.000000+00	0.000000	0.000000
WHEEL FORCES	-1.814474-07	0.000000	7.994650+00	0.000000	-1.585815-04

TIME = 2.0420352+01 SECONDS 130 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES	9.956519-01	0.000000	-1.2596045-09	0.000000
1.0000000+01 0.0000000				

X,Y,Z TRAJECTORY	9.7905143-01			
2.0420344+02 0.0000000				

DIRECTION COSINE MATRIX	1.0000000+00 0.0000000	1.5666417-09		
0.0000000 1.0000000+n	0.0000000	0.0000000		
-3.5666417-09 0.0000000	1.0000000+00			

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS	2.0935744-02	0.000000	-5.4359436-10	0.000000
-2.6465533-08 0.0000009				

WHEEL INDICATOR L2. 0 0 0

WHEEL-GROUND FORCES 1-BODY	J-BODY	K-BODY		
-3.1291238-08	0.000000	1.0209361+00		
-3.1291238-08	0.000000	1.0209361+00		
-3.1291226-08	0.000000	1.0209354+00		
-3.1291226-08	0.000000	1.0209354+00		

STEERING ANGLES DEGREES	0.000000	0.000000	0.000000	0.000000
NON LINEAR INERTIA FORCES BODY AXES	5.0362227-09	0.000000	-5.036416-08	0.000000
GRAVITY FORCES	1.426657-08	0.000000	-4.000000+00	0.000000
WHEEL FORCES	-1.251649-07	0.000000	4.083743+00	0.000000

TIME = 2.1991148+01 SECONDS 140 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES	2.2503933-02	0.0000000	-1.8652136-09	0.0000000
1.0000000+01 0.0000000				

X Y Z TRAJECTORY  
2.1991139+02

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0.0000000  
1.04943930+00

DIRECTION COSINE MATRIX  
1.000000+00 0.000000+00 1.5537000+09  
0.000000+00 1.000000+00 0.0730000  
-1.5539000-09 0.000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

5.0668617+0U 0.000000J -9.940584-01

0.0000000 0.0000000 -3.0785799+1J

WHEEL INDICATOR L2. 0 0 0

\*WHEEL-GROUND FORCES I-BODY  
-1.0890254-09 0.000000 1.5943050-03  
-1.0890254-09 0.000000 1.5943050-03  
-1.0889514-09 0.000000 1.5940666-03  
-1.0889514-09 0.000000 1.5940666-03

STEERING ANGLES DEGREES 0.000000 J-BODY

NON LINEAR INERTIA FORCES BODY AXES 1.678986+10

0.0000000 -7.460854-08

0.0000000 0.0000000 0.0000000 0.0000000

GRAVITY FORCES

6.215600-09 0.000000 -4.000000000 0.0000000

-4.355954-09 0.000000 6.376743-03 0.0000000 -3.078580-05 0.0000000

WHEEL FORCES

TIME = 2.3561944+01 SECONDS 150 TIME INTERVALS 150 SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.000000 -9.930323-01 0.0000000 -1.0084507+10 0.0000000

X Y Z TRAJECTORY

2.3561934+02 0.000000 1.0241338+00

DIRECTION COSINE MATRIX  
1.000000+00 0.000000 1.3503996+09  
0.000000 1.000000+00 0.0000000  
1.3503996-09 0.000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-2.7833486-08 0.000000 -2.4146572-02 0.0000000C 9.336743+10 0.0000000

WHEEL INDICATOR L2. 0 0 0

\*WHEEL-GROUND FORCES I-BODY  
-2.5682802-08 0.000000 9.7585332-01  
-2.5682802-08 0.000000 9.7585332-01  
-2.5682797-08 0.000000 9.7585355-01  
-2.5682797-08 0.000000 9.7585355-01

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UEMO PERIOD 20P1 X(3)=1

STEERING ANGLES DEGREES	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
NON LINEAR INERTIA FORCES	BODY AXES	-3.201143-09	0.000000	-3.203380-06	0.000000	0.000000
GRAVITY FORCES		-5.401599-09	0.000000	-4.000000+00	0.000000	0.000000
WHEEL FORCES		-1.027312-07	0.000000	3.901440+00	0.000000	9.536743-05

TIME = 2.5132741+01	SECONDS	160 TIME INTERVALS	1SUB INTERVALS			
BODY	TRANSLATIONAL AND ANGULAR VELOCITIES					
1.000000+01	0.000000	-2.5717363-02	0.0000000	1.133388-09	0.0000000	
X,Y,Z TRAJECTORY						
2.5132729+02	0.000000	1.0483989-03				
DIRECTION COSINE MATRIX						
1.000000+00	0.000000	-1.0534182-09				
0.000000	1.0000000+00	0.0000000				
1.0534182-09	0.0000000	1.0000000+00				
BODY	TRANSLATIONAL AND ANGULAR ACCELERATIONS					
-3.8636228-08	0.0000000	9.9813876-01	0.0000000	-1.0454456-09	0.0000000	
WHEEL INDICATOR L2,	0 0 0					
WHEEL-GROUND FORCES	I-BODY	J-BODY	K-BODY			
	-3.7611958-08	0.000000	1.09981387+00			
	-3.7611958-08	0.000000	1.09981387+00			
	-3.7611957-08	0.000000	1.09981389+00			
	-3.7611957-08	0.000000	1.09981389+00			
STEERING ANGLES DEGREES	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	
NON LINEAR INERTIA FORCES	BODY AXES	1.16580-10	0.000000	4.533435-08	0.000000	0.000000
GRAVITY FORCES		-4.213673-09	0.000000	-4.0000000+00	0.000000	0.000000
WHEEL FORCES		-1.504478-07	0.000000	7.992555+00	0.000000	-1.045496-04
TIME = 2.6703537+01	SECONDS	170 TIME INTERVALS	1SUB INTERVALS			
BODY	TRANSLATIONAL AND ANGULAR VELOCITIES					
1.000000+01	0.000000	9.9903090-01	0.0000000	6.4125660-10	0.0000000	
X,Y,Z TRAJECTORY						
2.6703523+02	0.000000	9.7263123-01				

DEMO PERIOD=20PI X(3)=1

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DIRECTION COSINE MATRIX  
 1.000000+00 0.000000 -1.7132872-11  
 0.000000 1.000000+00 0.000000  
 1.7132872-11 0.000000 1.000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 \*2.8381263-08 0.000000 2.735999-02 0.0000000

#WHEEL INDICATOR L2, 0 0 0

#WHEEL-GROUND FORCES I-BODY  
 -2.7723502-06 0.000000 J-BODY K-BODY  
 -2.7723502-08 0.000000 1.0273560+00  
 -2.7723490-08 0.000000 1.0273560+00  
 -2.7723490-08 0.000000 1.0273560+00

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -2.562541-09 0.000000 2.565026-08 0.000000 0.000000

GRAVITY FORCES -6.053149-11 0.000000 -4.0000000 0.000000 0.000000

WHEEL FORCES -1.108940-07 0.000000 4.109424+00 0.000000 2.641678-04 0.000000

TIME 2.8274333+01 SECONDS 180 TIME INTERVALS 15UB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.000000+01 0.000000 2.8929304-02 0.0000000 3.081286681-10 0.0000000

X,Y,Z TRAJECTORY  
 2.8274316+02 0.0000000 1.9978486+00

DIRECTION COSINE MATRIX  
 1.000000+00 0.000000 8.3744690-10  
 0.000000 1.000000+00 0.000000  
 -8.3744690-10 0.0000000 1.000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -4.2308125-10 0.000000 -9.9786134-01 0.0000000 -3.0133873-10 0.0000000

#WHEEL INDICATOR L2, 0 0 0

#WHEEL-GROUND FORCES I-BODY  
 -1.2495239-09 0.000000 J-BODY K-BODY  
 -1.2495239-09 0.000000 2.1387338-03  
 -1.2494717-09 0.000000 2.1387338-03  
 -1.2494717-09 0.0000000 2.1386146-03

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -4.412145-11 0.000000 1.0225147-08 0.000000 0.000000 0.000000

DEMO PERIOD=20PI X(3)=1

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GRAVITY FORCES 3.3497880-09 0.0000000 -4.000000+00 0.000000 0.000000  
WHEEL FORCES +4.997991-09 0.0000000 0.554697-03 0.000000 -3.013387-05 0.000000

TIME = 2.9446129+01 SECONDS 190 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.000000+01 0.0000000 -9.9874632-01 0.0000000 -1.00851081-10 0.0000000

X,Y,Z TRAJECTORY 2.9845109+02 0.0000000 1.0305511+00

DIRECTION COSINE MATRIX  
1.000000+00 0.0000000 9.982879-10  
0.0000000 1.0000000+00 0.0000000  
-9.4882879-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.6986449-08 0.0000000 -1.0563846-02 0.0000000 -1.6975403-09 0.0000000

WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES I-BODY  
-2.7826910-08 0.0000000 9.6943628-01  
-2.7826910-08 0.0000000 9.6943628-01  
-2.7826897-08 0.0000000 9.6943604-01  
-2.7826897-08 0.0000000 9.6943604-01

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000  
NON LINEAR INERTIA FORCES BODY AXES -4.335000-10 0.000000 -4.340433-09 0.000000 0.000000

GRAVITY FORCES 3.0795315-09 0.0000000 -4.000000+00 0.000000 0.000000  
WHEEL FORCES -1.113076-07 0.0000000 3.077745+00 0.000000 -1.697540-04 0.000000

TIME = 3.1415926+01 SECONDS 200 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.000000+01 0.0000000 -3.2139776-02 0.0000000 3.01618014-10 0.0000000

X,Y,Z TRAJECTORY 3.1415902+02 0.0000000 2.4133779-03

DIRECTION COSINE MATRIX  
1.000000+00 0.0000000 9.5594119-10  
0.0000000 1.000000+00 0.0000000

DEMO PERIOD=20PI X(3)=1

-9.5544119-1U 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-4.0654040-06 0.0000000 9.9757302-01 0.0000000

WHEEL INDICATOR L2. 0 0 0 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
-4.1620148-06 0.000000 1.9975740+00  
-4.1620148-06 0.000000 1.9975740+00  
-4.1620137-06 0.000000 1.9975737+00  
-4.1620137-06 0.000000 1.9975737+00

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000  
NON LINEAR INERTIA FORCES BODY AXES 4.064784-11 0.000000 1.264721-08 0.000000 0.000000  
GRAVITY FORCES 3.023765-09 0.000000 -4.0000000+00 0.000000 0.000000  
WHEEL FORCES -1.664806-07 0.000000 7.990295+00 0.000000 -3.070031-04 0.000000

FIN

RUNID: SKK220 ACCOUNT: SKA PROJECT: ROVER  
TIME: 00:07:24.790 IN: 26 OUT: 0 PAGES: 50  
INITIATION TIME: 19:26:18-APR 1.1970  
TERMINATION TIME: 19:39:06-APR 1.1970  
CORE-SECONDS: 1292  
IO COUNT: 119  
CHARGE: 50.145

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6 XQT SK3190.ADS  
 N50=1,SA=4\*1.58=4\*30.5=4\*10.,MH=1.5H=1.0,UM=10.,  
 Y=4.,100000.,100000.,200000.,  
 Z=100.,100.,-2.,100.,-100.,-2.,-100.,-100.,-100.,-2.,  
 NINT=400.,DELTHM=.07853982,IPHT=20,G0=-10.,RW=10.,  
 SEND

## SPRUNG MASS MATRIX (NO WHEELS)

XBAR= 0.0000000	YBAR= 0.0000000	ZBAR= 0.0000000	
4.0000000+00	0.0000000	0.0000000	0.0000000 0.0000000
0.0000000	4.0000000+00	0.0000000	0.0000000 0.0000000
0.0000000	0.0000000	4.0000000+00	0.0000000 0.0000000
0.0000000	0.0000000	0.0000000	0.0000000 0.0000000
0.0000000	0.0000000	0.0000000	1.0000000+05 0.0000000
0.0000000	0.0000000	0.0000000	0.0000000 1.0000000+05
0.0000000	0.0000000	0.0000000	0.0000000 0.0000000
			2.0000000+05

MOMENT OF INERTIA TENSOR ABOUT CG

Ixx= 1.0000000+05	Iyy= 1.0000000+15	Izz= 2.0000000+05	Ixy= 0.0000000	Ixz= 0.0000000	Iyz= 0.0000000
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## ROTATION VECTOR &amp; PRINCIPAL INERTIAS

PRINCIPAL INERTIA= 1.0000000+05	I=0.0000000+00	0.0000000 0.0000000
PRINCIPAL INERTIA= 1.0000000+05	0.0000000	1.0000000+00 0.0000000
PRINCIPAL INERTIA= 2.0000000+05	0.0000000	0.0000000 1.0000000+00

CG RELATIVE TO WHEEL CENTER ORIGIN AT GROUND AT TIME=0 (BODY COORDINATES) ASSUMING WHEELS HAVE BEEN TRIMMED

X= 0.000000	Y= 0.000000	Z= 1.000000+01
-------------	-------------	----------------

TIME = 0.0000000	SECONDS	TIME INTERVALS	ISUB INTERVALS
BODY TRANSLATIONAL AND ANGULAR VELOCITIES			
1.0000000+01 0.0000000	0.0000000	0.0000000	0.0000000
X,Y,Z TRAJECTORY	0.0000000	0.0000000	0.0000000
DIRECTION COSINE MATRIX	1.000000+00	0.0000000	0.0000000

DEMO PERIOD=2.0PI X(3)=1

0.000000 1.0000000+00 0.000000  
0.000000 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-3.9737293-08 0.0000000 9.9998721-01 0.0000000

WHEEL INDICATOR L2, 0 0 0 0

WHEEL-GROUND FORCES 1-BODY J-BODY K-BODY  
-3.9737294-C8 0.000000 1.0000000 1.0000000+00  
-3.9737294-U8 0.000000 1.0000000 1.0000000+00  
-3.9737294-O8 0.000000 1.0000000 1.0000000+00  
-3.9737294-P8 0.000000 1.0000000 1.0000000+00

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES 0.000000 0.000000 0.000000 0.000000

GRAVITY FORCES 0.000000 0.000000 0.000000 0.000000

WHEEL FORCES -1.589492-07 0.000000 7.999949+00 0.000000 -2.00779010-04 0.000000

TIME = 1.5707964+00 SECONDS 20 TIME INTERVALS 1 SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 1.00002323+00 0.0000000 6.30420119-11 0.0000000

X,Y,Z TRAJECTORY  
1.5707963+01 0.0000000 9.9957618-01

DIRECTION COSINE MATRIX

1.000000+00 0.000000 -3.5349890-10  
0.000000 1.0000000+00 0.000000  
3.5349890-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.7418023-08 0.0000000 4.1100303-04 0.0000000 -2.7942657-09 0.0000000

WHEEL INDICATOR L2, 0 0 0 0

WHEEL-GROUND FORCES 1-BODY J-BODY K-BODY  
-2.7001468-08 0.000000 1.0004110+00  
-2.7001468-08 0.000000 1.0004110+00  
-2.7001468-08 0.000000 1.0004110+00  
-2.7001468-08 0.000000 1.0004110+00

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -2.5222671-U 0.000000 2.521681-U+ 0.000000 0.000000 0.000000

GRAVITY FORCES -1.413996-09 0.000000 4.000000+00 0.000000 0.000000 0.000000

DEMO PERIOD=2.0PI X(3)=1

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## WHEEL FORCES

TIME = 3.1415929+00 SECONDS 40 TIME INTERVALS 1SUB INTERVALS  
-1.080059-07 0.000000 4.001644+00 0.000000 -2.0794266-04 0.000000**BODY TRANSLATIONAL AND ANGULAR VELOCITIES**  
1.0000000+01 0.0000000 A.0660544-04 0.0000000 -4.2729111-10 0.0000000**X,Y,Z TRAJECTORY**  
3.1415923+01 0.0000000 1.9999502+00

## DIRECTION COSINE MATRIX

1.0000000+00 0.0000000 -1.1934409-09  
0.0000000 1.0000000+01 0.0000000  
1.1934409-09 0.0000000 1.0000000+00**BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS**  
-1.01930962-09 0.0000000 -9.9999999-01 0.0000000 2.6511072-10 0.0000000

## WHEEL INDICATOR L2, 1 1 1

**WHEEL-GROUND FORCES** 1-BODY  
0.0000000 0.0000000 K-BODY  
0.0000000 0.0000000  
0.0000000 0.0000000  
0.0000000 0.0000000  
0.0000000 0.0000000

## STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000

**NON LINEAR INERTIA FORCES** BODY AXES 1.516480-12 0.000000 -1.080076-08 0.000000 0.000000 0.000000

## GRAVITY FORCES

-5.251140-09 0.000000 -4.4000000+00 0.000000 9.547527-10 0.000000

## WHEEL FORCES

0.0000000 0.0000000 0.0000000 0.0000000 0.0000000

TIME = 4.7123891+00 SECONDS 60 TIME INTERVALS 1SUB INTERVALS

**BODY TRANSLATIONAL AND ANGULAR VELOCITIES**  
1.0000000+01 0.0000000 -1.0002079+00 0.0000000 -6.5052627-10 0.0000000**X,Y,Z TRAJECTORY**  
4.7123883+01 0.0000000 1.0012041+00**DIRECTION COSINE MATRIX**  
1.0000000+00 0.0000000 -1.4858811-09  
0.0000000 1.0000000+01 0.0000000  
1.4858810-09 0.0000000 1.0000000+00

DEMO PERIOD=20PI X(3)=1

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.7984196-08 0.0000000 0.0000000 0.0000000 -1.3923645-09 0.0000000

WHEEL INDICATOR L2, 0 0 0 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
-2.5847652-08 0.0000000 9.9878298-01  
-2.5847652-08 0.0000000 9.9878298-01  
-2.5847655-08 0.0000000 9.9878322-01  
-2.5847655-08 0.0000000 9.9878322-01

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES -2.602646-09 0.000000 -2.602105-09 0.000000 0.000000

GRAVITY FORCES -5.943524-09 0.000000 -4.000000+00 0.000000 0.000000

WHEEL FORCES -1.0333906-07 0.000000 3.995132+00 0.000000 -1.392365-04 0.000000

TIME = 6.2431055+00 SECONDS 80 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 2.5315919-10 0.0000000

X,Y,Z TRAJECTORY  
6.2831843+01 0.0000000 4.8807997-05

DIRECTION COSINE MATRIX

1.0000000+00 0.0000000 -1.3669585-09  
0.0000000 1.0000000+00 0.0000000  
1.3669585-09 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-3.8369468-08 0.0000000 9.9993834-01 0.0000000 -1.5830494-09 0.0000000

WHEEL INDICATOR L2, 0 0 0 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
-3.7002917-08 0.0000000 1.9999382+00  
-3.7002917-08 0.0000000 1.9999382+00  
-3.7002920-08 0.0000000 1.9999385+00  
-3.7002920-08 0.0000000 1.9999385+00

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES 1.633565-12 0.000000 1.012637-09 0.000000 0.000000

GRAVITY FORCES -5.467834-09 0.000000 -4.000000+00 0.000000 0.000000

WHEEL FORCES -1.480117-07 0.000000 7.999753+00 0.000000 -1.033646-04 0.000000

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TIME = 7.853981900 SECONDS 100 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.0000000 1.0001829+00 0.0000000 9.6447289-10 0.0000000

X,Y,Z TRAJECTORY  
 7.8539795+01 0.0000000 9.9796346-01

DIRECTION COSINE MATRIX  
 1.0000000+00 0.0000000 -4.9420038-10  
 0.0000000 1.0000000+00 0.0000000  
 6.9420038-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -2.8341485-08 0.0000000 2.0237267-03 0.0000000 -3.5095215-09 0.0000000

#WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
 -2.6682636-08 0.000000 1.0020237+00  
 -2.6682636-08 0.000000 1.0020237+00  
 -2.6682636-08 0.000000 1.0020238+00  
 -2.6682636-08 0.000000 1.0020238+00

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -3.858597-09 0.000000 3.657892-08 0.000000 0.000000

GRAVITY FORCES -2.776802-09 0.000000 -4.0000000+00 0.000000 0.000000

WHEEL FORCES -1.067305-07 0.000000 4.0000000+00 0.000000 -3.509521-04 0.000000

TIME = 9.424778200 SECONDS 120 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.0000000 2.4190573-03 0.0000000 3.7514683-10 0.0000000

X,Y,Z TRAJECTORY  
 9.4247746+01 0.0000000 1.9999000+00

DIRECTION COSINE MATRIX  
 1.0000000+00 0.0000000 6.3050472-12  
 0.0000000 1.0000000+00 0.0000000  
 -6.3050472-12 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 5.3975442-12 0.0000000 -9.9999999-01 0.0000000 -6.98136843-18 0.0000000

DEMO PERIOD=2\*P1 X(3)=1

WHEEL INDICATOR L2, 1 1 1

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WHEEL-GROUND FORCES	1-BODY	J-BODY	K-BODY
0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000

STEERING ANGLES DEGREES	0.0000000	G+00000000	0.0000000	0.0000000			
NON LINEAR INERTIA FORCES	BODY AXES	-3.993007-12	0.000000	1.653646-08	0.000000	0.000000	
GRAVITY FORCES		2.774221-11	0.000000	-4.400000+00	0.000000	-5.044038-12	0.000000
WHEEL FORCES		0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

TIME = 1.09955575+01 SECONDS 140 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES	1.0000000+01	0.0000000	-1.0001571+00	0.0000000	-7.38864992-10	0.0000000
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X,Y,Z TRAJECTORY	1.0995570+02	0.0000000	1.0028155+00
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DIRECTION COSINE MATRIX	1.0000000+00	0.0000000	3.5572933-10
	0.0000000	1.0000000+00	0.0000000
	-3.5572933-10	0.0000000	1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS	-2.8046520-08	0.0000000	-2.8283149-03	0.0000000	-1.1444092-09	0.0000000
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WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES	1-BODY	J-BODY	K-BODY
-2.7663263-08	0.0000000	9.9717175-01	
-2.7663263-08	0.0000000	9.9717175-01	
-2.7663264-08	0.0000000	9.9717163-01	
-2.7663264-08	0.0000003	9.9717163-01	

STEERING ANGLES DEGREES	0.0000000	0.0000000	0.0000000	0.0000000			
NON LINEAR INERTIA FORCES	BODY AXES	-2.955944-09	0.000000	-2.95540-08	0.000000	0.000000	
GRAVITY FORCES		1.422917-09	0.000000	-4.000000+00	0.000000	0.000000	
WHEEL FORCES		-1.06531-07	0.000000	3.986657+00	0.000000	-1.14409-U4	0.000000

DEMO PERIOD=2\*PI X(3)=1

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TIME = 1.07566371+01 SECONDS 160 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 -3.2249112-03 0.0000000 -6.0771923-10 0.0000000X,Y,Z TRAJECTORY  
1.2566365+02 0.0000000 1.00025810-04

DIRECTION COSINE MATRIX

1.0000000+00	0.0000000	-4.6001887-10
0.0000000	1.0000000+00	0.0000000
4.6001887-10	0.0000000	1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-3.9278822-08	0.0000000	9.9988690-01
		0.0000000

WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY

-3.8816198-08	0.0000000	1.09978869+00
-3.8816198-08	0.0000000	1.09978869+00
-3.8816198-08	0.0000000	1.09978870+00
-3.8816198-08	0.0000000	1.09978870+00

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -1.042006-11 0.0000000 -3.231117-C8 0.0000000 0.0000000

GRAVITY FORCES -1.840075-09 0.0000000 -4.0000000+00 0.0000000 0.0000000

WHEEL FORCES -1.552648-07 0.0000000 7.099548+00 0.0000000 -1.0811981-04 0.0000000

TIME = 1.04137167+01 SECONDS 180 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.0000000 1.0001307+00 0.0000000 -5.0765177-11 0.0000000X,Y,Z TRAJECTORY  
1.4137158+02 0.0000000 9.9635217-01

DIRECTION COSINE MATRIX

1.0000000+00	0.0000000	-1.5331468-09
0.0000000	1.0000000+00	0.0000000
1.5331468-09	0.0000000	1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-2.7337162-C8	0.0000000	3.6350191-03
		0.0000000

WHEEL INDICATOR L2, 0 0 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY

DEMO PERIOD=2.0PI X(13)=1

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-2.5862785-08	0.000000	0.000000	1.0036349+00
-2.5862785-06	0.000000	0.000000	1.0036349+00
-2.5862791-08	0.000000	0.000000	1.0036352+00
-2.5862791-08	0.000000	0.000000	1.0036352+00

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES 2.350914-10 0.000000 -2.350607-09 0.000000 0.000000 0.000000

GRAVITY FORCES -6.132587-09 0.000000 -4.000000+00 0.000000 0.000000 0.000000

WHEEL FORCES -1.034512-07 0.000000 4.014540+00 0.000000 -3.0204346-04 0.000000

TIME = 1.5707964+01 SECONDS 200 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES	1.0000000+01	0.0000000	4.0300200-03	0.0000000	3.9268721-10	0.0000000
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X,Y,Z TRAJECTORY	1.5707951+02	0.0000000	1.9998473+00			
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DIRECTION COSINE MATRIX

1.000000+00	0.0000000	-1.05931284-09				
0.0000000	1.0000000+00	0.0000000				
1.05931284-09	0.0000000	1.0000000+00				

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-1.5947110-09	0.0000000	-9.99999999-01	0.0000000	-1.02173134-17	0.0000000
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WHEEL INDICATOR L2, 1 1 1

WHEEL-GROUND FORCES 1-BODY	0.000000	0.000000	J-BODY	0.000000	K-BODY	0.000000
	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES -6.963164-12 0.000000 1.0727924-08 0.000000 0.000000 0.000000

GRAVITY FORCES -7.009765-09 0.000000 -4.000000+00 0.000000 1.0274503-09 0.000000

WHEEL FORCES 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000

TIME = 1.7278760+01 SECONDS 220 TIME INTERVALS 1SUB INTERVALS

UENO PERIOD=20PI A(3)=1

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BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.000000+01 0.000000 -1.0001037+00 0.000000 3.0260306-12 0.000000

X,Y,Z TRAJECTORY  
 1.7278744+02 0.000000 1.0044253+00

DIRECTION COSINE MATRIX

1.000000+00	0.0000000	-5.6261797-10
0.0000000	1.0000000+01	0.0000000
5.6261797-10	0.0000000	1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

*2.7284816-08	0.0000000	-4.4381171-01
		0.0000000

WHEEL INDICATOR L2. 0 0 0

WHEEL-GROUND FORCES I-BODY	J-BODY	K-BODY
-2.6725222+08	0.0000000	9.956183-01
-2.6725222+08	0.0000000	9.956183-01
-2.6725228+08	0.0000000	9.956195-01
-2.6725228+08	0.0000000	9.956195-01

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES 1.210538+11 0.000000 1.210412+10 0.000000 0.000000

GRAVITY FORCES

-2.250472+09	0.000000	-4.000000+00	0.000000	0.000000
-1.069009+07	0.000000	3.982248+00	0.000000	2.000000

WHEEL FORCES

TIME = 1.0049556+01 SECONDS 240 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.000000+01 0.000000 -4.8351530-03 0.0000000 3.2237570-11 0.0000000

X,Y,Z TRAJECTORY  
 1.8849537+02 0.000000 1.5426913-04

DIRECTION COSINE MATRIX	I-BODY	J-BODY	K-BODY
1.000000+00	0.000000	-4.6417917-12	1.9993330+00
0.0000000	1.0000000+01	0.0000000	1.9993330+00
4.6417917-12	0.0000000	1.0000000+00	1.9993330+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

*3.970796-08	0.0000000	9.9983296-01	0.0000000

WHEEL INDICATOR L2. 0 0 0

WHEEL-GROUND FORCES I-BODY	J-BODY	K-BODY
-3.9726317+08	0.0000000	1.9993330+00
-3.9726317+08	0.0000000	1.9993330+00
-3.9726304-08	0.0000000	1.9993330+00

DEMO PERIOD=2@P1 X(3)=1

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-3- 9726304-08 0.000000 10998330400

STEERING ANGLES DEGREES	0.000000	0.000000	0.000000	0.000000	
NON LINEAR INERTIA FORCES	BODY AXES	6.234943-13	0.000000	1.289503-04	0.000000
GRAVITY FORCES		-1.0456717-11	0.000000	-4.0000000000	0.000000
WHEEL FORCES		-1.0589052-07	0.000000	1.9993320000	0.000000

TIME = 2.0420351001 SECONDS TIME INTERVALS 1000 INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 $1.00000000$   $0.0000000$   $1.00000000$   $0.00000000$   $1.00000000$

X,Y,Z TRAJECTORY

DIRECTION COSINE MATRIX  
 $\begin{array}{cc} 1.000000+00 & 0.000000 \\ 0.000000+00 & 1.000000 \end{array}$

0.0000000 1.0000000+00 0.000000  
1.6232066-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
~~-2.7553564-08~~ 0.000000 5.244823-03 0.0000000 -3.02

WHEEL INDICATOR L2. 0 0 0 0

WHEEL-GROUND FORCES	1-BODY	J-800 Y	K-BODY
-2.7261627-08	0.0000000	1.0052448+00	
-2.7261627-08	0.0000000	1.0052448+00	
-2.7261622-06	0.0000000	1.0052448+00	
-2.7261622-08	0.0000000	1.0052448+00	

STEERING ANGLE DEGREES 0 0000000 0 0000000 0 0000000

STEERING ANGLES DEGREES	WHEEL FORCES	WHEEL TORQUE	WHEEL POSITION	WHEEL VELOCITY	WHEEL ACCELERATION	
NON LINEAR INERTIA FORCES	BODY AXES	-5.194771-10	0.000000	5.184376-10	0.000000	0.000000
GRAVITY FORCES		-6.492834-10	0.000000	-4.000000+10	0.000000	0.000000

TIME = 2.1991149401 SECONDS TIME INTERVALS = 280 SUB INTERVALS

DEMO PERIOD=20PI  $\lambda(3)=1$ 

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X,Y,Z TRAJECTORY  
2.1991124+02 0.000000 1.9997920+00

DIRECTION COSINE MATRIX  
1.000000+00 0.000000 -4.1884305-10  
0.000000 1.000000+05 0.0000000U  
4.1884305-10 0.000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-4.1812698-10 0.000000 -9.9999999-01 0.0000000U

WHEEL INDICATOR L2, 1 1 1

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
0.000000 0.000000 0.000000  
0.000000 0.000000 0.000000  
0.000000 0.000000 0.000000  
0.000000 0.000000 0.000000

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BODY AXES 3.150679-12 0.000000 -5.506845-09 0.000000 0.000000 0.000000

GRAVITY FORCES -1.0442909-09 0.000000 -4.4000000+00 0.000000 3.350744-10 0.000000

WHEEL FORCES 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000

TIME = 2.3561946+01 SECONDS 300 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+01 0.000000 -1.0000478+00 0.0000000 4.0112075-10 0.000000U

X,Y,Z TRAJECTORY  
2.3561917+02 0.000000 1.0060336+00

DIRECTION COSINE MATRIX  
1.000000+00 0.000000 -6.2301851-10  
0.0000000 1.000000+01 0.0000000  
6.2301851-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.8167071-08 0.000000 -6.0463697-03 0.0000000 1.1539459-U9 0.0000000

WHEEL INDICATOR L2, U U O O

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
-2.6642887+06 0.000000 9.9395358-01  
-2.6642887-06 0.000000 9.9395358-01  
-2.6642891+06 0.000000 9.9395370-01  
-2.6642891-06 0.000000 9.9395370-01

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DEMO PERIOD=20PI X(3)=1

STEERING ANGLES DEGREES	0.0000000	0.0000000	0.0000000	0.0000000	
NON LINEAR INERTIA FORCES	BODY AXES	-3.604655-09	0.00000	-3.604483-08	0.00000
GRAVITY FORCES		-2.492074-09	0.00000	-4.000000000	0.00000
WHEEL FORCES		-1.065716-07	0.00000	1.975015+00	0.00000

TIME = 2.5132742401    SECONDS    320 TIME INTERVALS    15 SUB INTERVALS

## BODY TRANSLATIONAL AND ANGULAR VELOCITIES

ARMED SENSATION

2.5132710<sup>+02</sup> 0.0000000 2.1084899-04

DIRECTION COSINE MATRIX

0.0000000	1.0000000	0.0000000
1.2513013-07	0.0000000	1.0000000

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS

-3.084866688-08	0.0000000	9.999776333-01	0.0000000	-1.15830944-09	0.0000000
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WHEEL INDIA 12; 0 0 0

WHEEL-GROUND FORCES I-BD1 J-BD1 K-BD1 1.9997762+00  
-3.7232642-08 0.0000000

-30/232672+08 0.0000000  
-30/232672-08 0.0000000  
-30/232641+08 0.0000000  
-30/232641-08 0.0000000

STEERING ANGLES DEGREES    0.0000000    0.0000000    0.0000000

NON LINEAR INERTIA FORCES BODY AXES =1,2,10,3,-11 0.000000 -1.878255-08 0.000000 0.000

GRAVITY FORCES -5.005205e-09 0.000000 -4.000000e-09 0.000000 0.00

-1.409306-07 0.000000 WHEEL FORCES 7.9999105+00 0.000000 -1.05

TIME = 2.67033801 SECONDS 340 TIME INTERVALS 1000 INTERVALS

W. H. DUNN AND R. E. BROWN  
TRANSLATIONAL AND ANGULAR VELOCITIES

X,Y,Z TRAJECTORY

2.6703503+02 0.0000000 9.9313425-01

DEMO PERIOD=2 PI A(3)=1

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DIRECTION COSINE MATRIX  
 1.000000+00 0.0000000 0.0000000 -1.5364290-09  
 0.000000 1.0000000+00 0.0000000 0.0000000+00  
 1.5364290-09 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -2.7833299-08 0.0000000 6.8528950-03 0.0000000

WHEEL INDICATOR L2. 0 0 0

#HEEL-GROUND FORCES I-BODY J-BODY K-BODY  
 -2.5901064-08 0.0000000 1.00668527+00  
 -2.5901064-08 0.0000000 1.00668527+00  
 -2.5901068-08 0.0000000 1.00668531+00  
 -2.5901068-08 0.0000000 1.00668531+00

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -1.583218-04 0.0000000 1.583168-04 0.0000000 0.0000000

GRAVITY FORCES -6.145716-09 0.0000000 -4.036043-07 0.0000000 0.0000000 0.0000000

WHEEL FORCES -1.036043-07 0.0000000 4.027412-04 0.0000000 -2.145767-04 0.0000000

TIME = 2.8274335+01 SECONDS 360 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
 1.0000000+01 0.0000000 7.2472170-03 0.0000000 6.45846725-10 0.0000000

X,Y,Z TRAJECTORY  
 2.8274296+02 0.0000000 1.9997340+00

DIRECTION COSINE MATRIX  
 1.000000+00 0.0000000 -5.8887151-10  
 0.000000 1.0000000+00 0.0000000  
 5.8887151-10 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
 -5.9500169-10 0.0000000 -9.9999999-01 0.0000000 -4.7154536-17 0.0000000

WHEEL INDICATOR L2. 1 1 1

#HEEL-GROUND FORCES I-BODY J-BODY K-BODY  
 0.0000000 0.0000000 0.0000000  
 0.0000000 0.0000000 0.0000000  
 0.0000000 0.0000000 0.0000000  
 0.0000000 0.0000000 0.0000000

STEERING ANGLES DEGREES 0.0000000 0.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -2.697281-11 0.0000000 3.721316-06 0.0000000 0.0000000 0.0000000

DEMO PERIOD=20PI X(3)=1

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GRAVITY FORCES	-2.591035-U9	0.000000	-4.400000+UJ	0.000000	4.710472-10	0.000000
WHEEL FORCES	0.000000+0I	0.000000	0.000000	0.000000	0.000000	0.000000

TIME = 2.9845131+01 SECONDS 380 TIME INTERVALS 1SUB INTERVALS  
BODY TRANSLATIONAL AND ANGULAR VELOCITIES  
1.0000000+0I 0.0000000 -9.9998924+01 0.0000000 -1.427645U-10 U.0000000

X,Y,Z TRAJECTORY  
2.9845089+02 0.0000001 1.0076401+00

DIRECTION COSINE MATRIX  
1.0000000+0G 0.0000000 6.0064899-10  
0.0000000 1.0000000+0I 0.0000000  
-6.0064899-1U 0.0000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-2.7377088-08 0.0000000 -7.6529533-03 0.0000000 1.6021728+U9 U.0000000

WHEEL INDICATOR L2, 0 0 U 0

WHEEL-GROUND FORCES 1-BODY J-BODY K-BODY  
-2.7834976+08 0.0000000 9.9234711-01  
-2.7834976+08 0.0000000 9.9234711-01  
-2.7834973-08 0.0000000 9.9234699-01  
-2.7834973-08 0.0000000 9.9234699-01

STEERING ANGLES DEGREES 0.000000 C.0000000 0.0000000 0.0000000

NON LINEAR INERTIA FORCES BODY AXES -5.710516-10 0.000000 -5.710516-U9 0.000000 0.000000 0.000000

GRAVITY FORCES 2.402596-09 0.000000 -4.000000+U0 0.000000 0.000000 0.000000

WHEEL FORCES -1.113399-07 0.000000 3.969388+U0 0.000000 1.602173-04 0.000000

TIME = 3.1415926+01 SECONDS 400 TIME INTERVALS 1SUB INTERVALS

BODY TRANSLATIONAL AND ANGULAR VELOCITIES	1.0000000+0I	0.0000000 -3.0506625-U3	0.0000000 -7.1900597-10	0.0000000
X,Y,Z TRAJECTORY	3.1415882+02	0.000000	2.7706696-U4	

DIRECTION COSINE MATRIX  
1.0000000+0U 0.0000000 1.7021817-10  
0.0000000 1.0000000+U+ 0.0000000

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UEMO PERIOD=20PI X(3)=1

-3.7621817-10 0.000000 1.0000000+00

BODY TRANSLATIONAL AND ANGULAR ACCELERATIONS  
-4.0110217-06 0.000000 9.9971715-01 0.000000

WHEEL INDICATOR L2, U U U 0

WHEEL-GROUND FORCES I-BODY J-BODY K-BODY  
-4.0474654-08 0.000000 1.000000 1.000000  
-4.0474654-08 0.000000 1.000000 1.000000  
-4.0474640-06 0.000000 1.000000 1.000000  
-4.0474640-06 0.000000 1.000000 1.000000

STEERING ANGLES DEGREES 0.000000 0.000000 0.000000 0.000000

NON LINEAR INERTIA FORCES BUUY AXES -2.315390-11 0.000000 -2.0876024-U4 0.000000 0.000000

GRAVITY FORCES 1.480873-U9 0.000000 -4.000000+U0 0.000000 0.000000

WHEEL FORCES -1.618986-U7 0.000000 7.998869+U0 0.000000 -2.326965-U4 0.000000

6 FIN

RUNID: Sxk220 ACCOUNT: SKA

PROJECT: ROVER

TIME: 00:13:42+144

IN: 26 OUT: 0

PAGES: 50

INITIATION TIME: 18:36:52-APR 2.1970

TERMINATION TIME: 19:51:12-APR 2.1970

CORE-SECONDS: 2464

IO COUNT: 119

CHARGE: 95.737

BELLCOMM, INC.  
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Equations of Motion of the Lunar Roving Vehicle - Case 320  
DATE: July 30, 1970  
FROM: S. Kaufman

ERRATA

The Technical Memorandum TM-70-2031-1 dated March 31, 1970, requires the following corrections.

1. Page 14

a. Eq. 37  $\cos \omega h$  should read  $1 - \cos \omega h$

b.  $\{V\}_{i+h/2} = \{V\}_i + \frac{h}{4} \left( \{\dot{V}\}_i + \overset{(1)}{\{\dot{V}\}}_{i+h/2} \right)$   
should read  $\{V\}_{i+h/2} = \{V\}_i + \frac{h}{2} \overset{(1)}{\{\dot{V}\}}_{i+h/2}$

2. Appendix

Page 3

a.  $c x \phi$  should read  $x c \phi$  (2 places)

Page 7

a.  $\text{THET1} = EH * \text{OFF2} / (\text{ALX} - Z(1,1))^2$

should read  $\text{THET1} = DH * \text{OFF2} / (\text{ALY-Z}(2,1))^2$

b.  $\text{THET2} = -EH * \text{OFF1} / (\text{ALY-Z}(2,1))^2$

should read  $\text{THETA2} = -DH * \text{OFF1} / (\text{ALX-Z}(1,1))^2$

3. Various additions and corrections have been made to the FORTRAN coding. Linear damping has been replaced by damping force proportional to velocity to DAMC power. DAMC = 0 or blank in NAMELIST input implies DAMC = 1.0 (linear damping).

*S. Kaufman*

S. Kaufman

2031-SK-vh